PHYSICS 20

Module 7

Applications of Light

Distance Learning

Alberta EDUCATION

Physics 20

Module 7

Applications of Light

Alberta

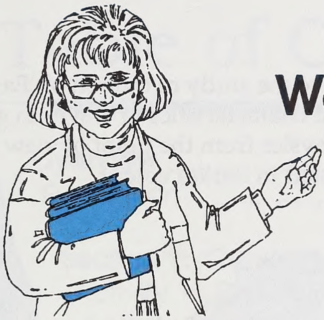
EDUCATION

Distance Learning

This document is intended for	
Students	✓
Teachers (Physics 20)	✓
Administrators	
Parents	
General Public	
Other	

Physics 20
Student Module
Module 7
Applications of Light
Alberta Distance Learning Centre
ISBN No. 0-7741-0839-8

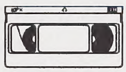
Cover Photo: PHOTO SEARCH LTD.



Welcome to Module 7!

We hope you'll enjoy your study of *Applications of Light.*

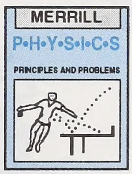
To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

Frame 48350A

When you see this icon, study the appropriate pages in your textbook.



Good Luck!

Course Overview

This course contains eight modules. The first four modules involve the study of motion on Earth and in the heavens. Modules 5, 6, and 7 investigate the properties and characteristics of waves in general and light waves. The last module is an introduction to nuclear physics from the point of view of risk/benefit analysis. The module you are working in is highlighted in darker colour.

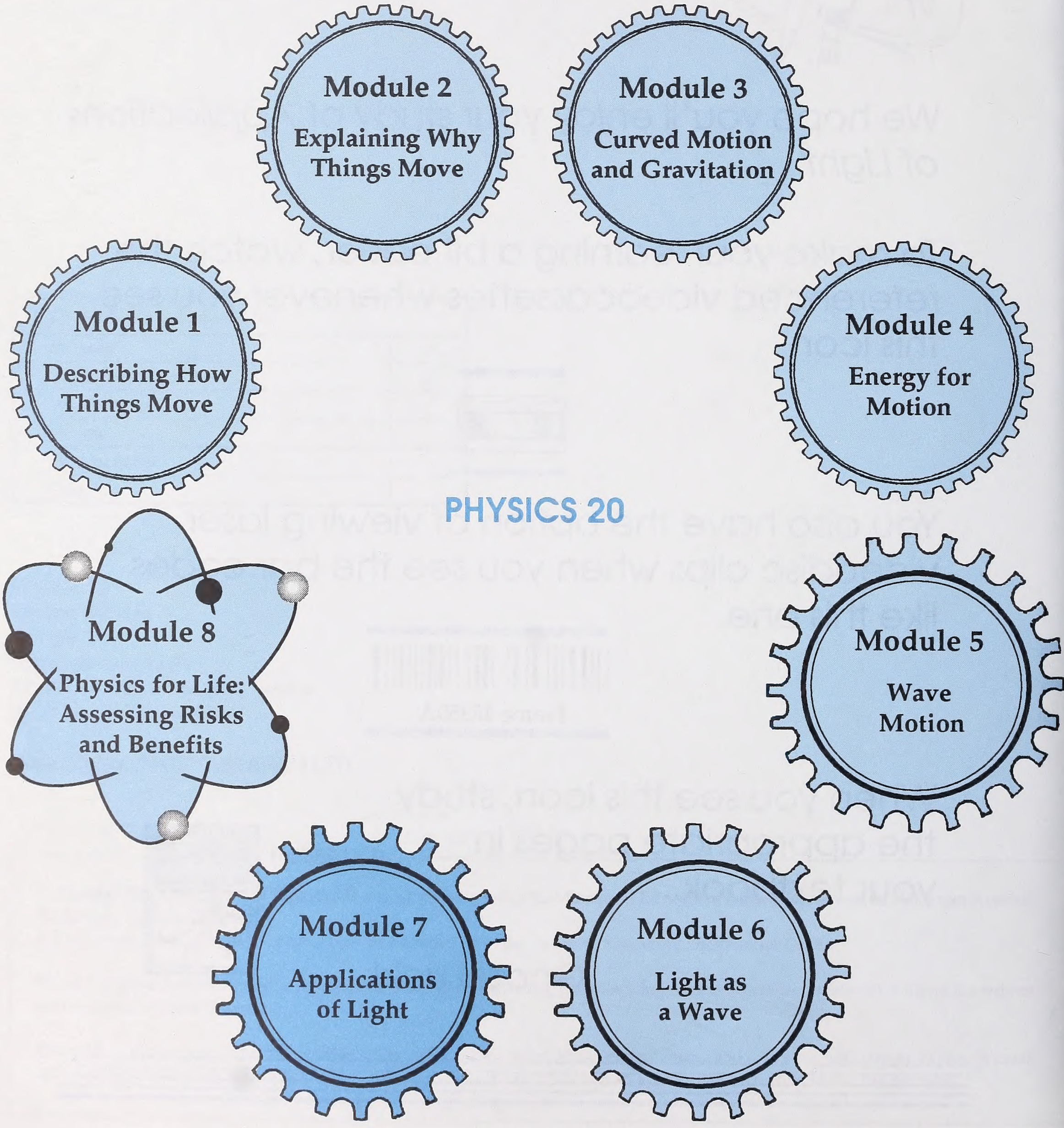


Table of Contents

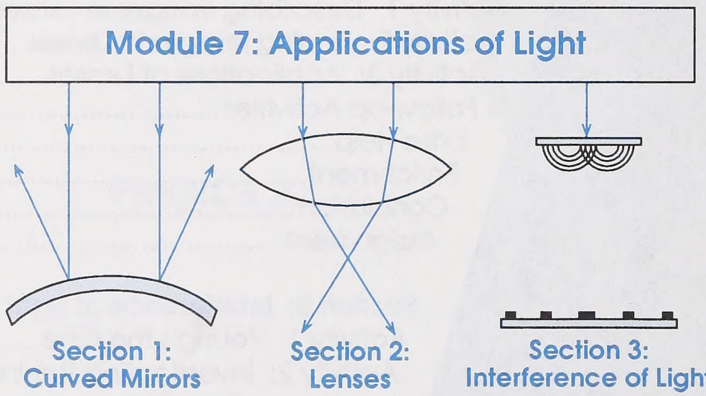
OVERVIEW

Imagine sitting in the driver's seat of your favourite sportscar. You adjust the rearview mirror, turn on the headlights, and turn on the CD player.

All of the devices listed – the rearview mirror, the headlights, and the CD player – use the properties of light. Light is reflected from the flat surface of the rearview mirror and the curved reflector in the headlight. Light is also refracted by the curved lens of the headlight. The CD player diffracts, reflects, and causes interference in a laser beam as the digital information on the disc is converted to music.

Are there any similarities between the diffraction and interference of sound waves and light waves? How does light behave when it reflects and refracts from curved surfaces?

In this module you will answer these questions and explore other applications of light. You will also apply the properties of light to the most sophisticated optical device that you have – your eyes.



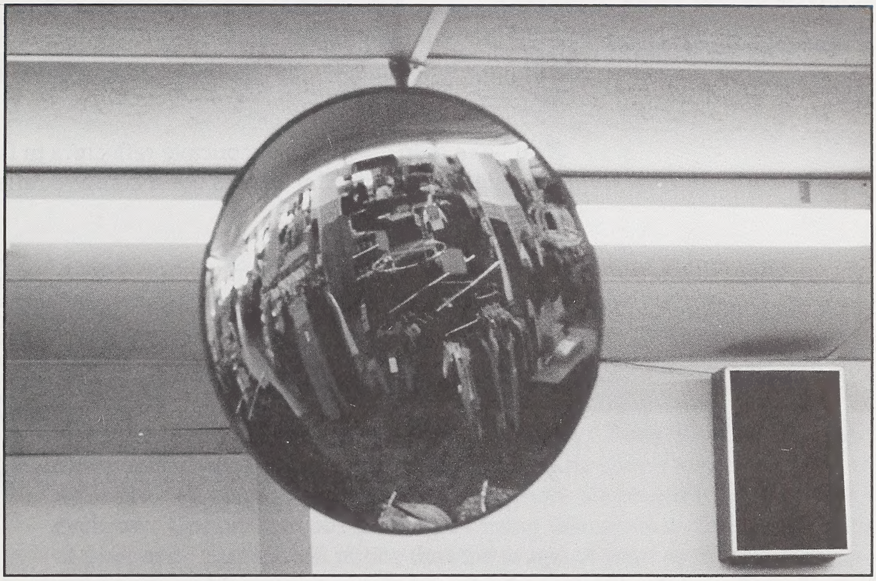
Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete three section assignments. The mark distribution is as follows:

Section 1 Assignment	34 marks
Section 2 Assignment	33 marks
Section 3 Assignment	33 marks
TOTAL	**100 marks**

Section

1 Curved Mirrors



When was the last time that you noticed a security mirror in a store? When you looked into this mirror, you probably noticed that your image was distorted. Why do stores use these mirrors?

In this section you will examine the images created by curved mirrors. You will learn why the images are often distorted. You will also learn to draw diagrams and apply equations to locate these distorted images.

Activity 1: Describing Images

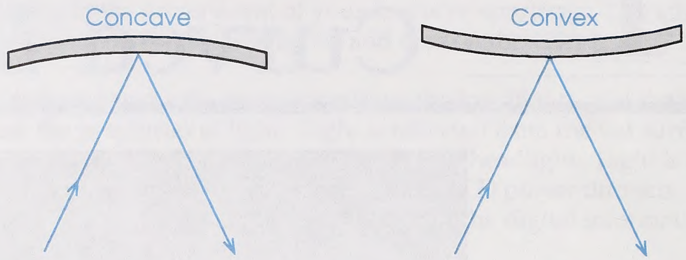
1. Why are the security mirrors in stores curved? Why aren't plane mirrors used?

2. Objects in security mirrors are actually closer than they appear. Have you ever noticed this effect before? If so, where?

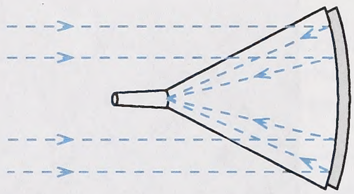
convex mirror – reflects light from its outer surface which curves out towards the viewer

concave mirror – reflects light from its inner surface which curves away from the viewer

The examples discussed so far have all involved **convex mirrors**. The effects of **concave mirrors** can also be easily observed.



You have seen examples of concave reflectors in flashlights, headlights, and satellite dishes. Satellite dishes use a concave reflector to gather microwaves at one point.



3. How do flashlights or headlights in a car differ from satellite dishes in their use of concave reflectors?

Investigation: The Common Spoon Reflector

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☐ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

You will examine the images formed on both surfaces of a spoon.

Materials

You will need to obtain one smooth, shiny spoon from your kitchen. A large soup spoon will work best.

Procedure and Observations

4. Which side of the spoon is convex and which side is concave?

5. With the handle of the spoon pointing down, observe the image of your face when the spoon is held 20 cm from your face. Do this for both the convex and concave side of the spoon. Sketch what your face looked like in the following diagrams of the spoon.

Spoon as a Concave Mirror

Spoon as a Convex Mirror

6. Hold the spoon at arm's length from your body. Turn the spoon so that the concave side is facing you. Slowly move the spoon towards your right eye. As you move the spoon closer, note the position of your right eyebrow. Continue to observe as you bring the spoon within centimetres of your eye. You should notice that the image of your eyebrow will disappear and then reappear in an upright position. Do you think that all concave mirrors will do this? Make a prediction.

Check your answers by turning to the Appendix, Section 1: Activity 1.

Activity 2: Finding Images

In order to understand how an image can be formed in a curved mirror, you must first understand some terminology.

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

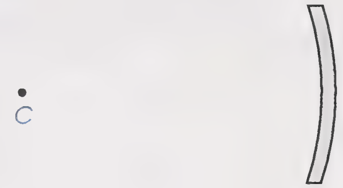
Read pages 370 and 371 in your textbook.

focal point – the point on the principal axis to which parallel incident rays will converge

principal axis – a line perpendicular to the centre of a mirror or lens

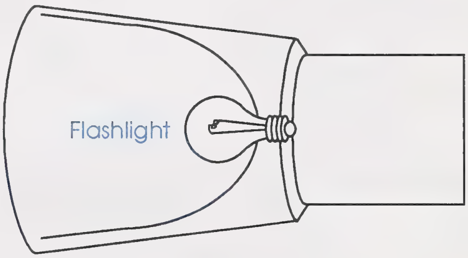
centre of curvature – the centre of the spherical surface that makes a curved mirror or lens

1. Complete the following diagram by sketching and labelling the **focal point** and the **principal axis**. Assume that point C is the **centre of curvature**.



2. A ray of light from a distant object strikes a spherical mirror parallel to the principal axis. What is the one point that this ray will most likely pass through or near?

3. Use a ray diagram to show how a flashlight uses a concave mirror to send out a nearly parallel beam of light rays by locating the filament of the lamp at the focus.



virtual image – an image from which light rays appear to originate. A virtual image cannot be formed on a screen.

real image – an image formed by the convergence of actual light rays. A real image can be formed on a screen.

The image formed by a plane mirror is called a **virtual image**. Images caused by curved surfaces may be virtual, but **real images** can also be found.

4. What is the main difference between a virtual image and a real image?

In the following investigation you will be studying the types of images formed by both concave and convex mirrors.

For the next investigation you will require some base material for supporting the mirror. You may use plasticine, putty, or something similar. If you don't have access to something like that, you may wish to make some play dough. A recipe is provided for you.

- 1 cup of flour
- 1 cup of water
- 1/4 cup of salt
- 1 tablespoon of cooking oil
- 1 tablespoon of cream of tartar

Mix all the ingredients together in a pot and stir constantly over medium heat until the mixture is too thick to stir any longer. Remove the pot from the stove. When the play dough has cooled, remove it from the pot and store it in a sealed plastic container in the refrigerator.

Investigation: Images Formed by Curved Mirrors

Purpose

In this investigation you will discover the characteristics of images formed by convex and concave mirrors.

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

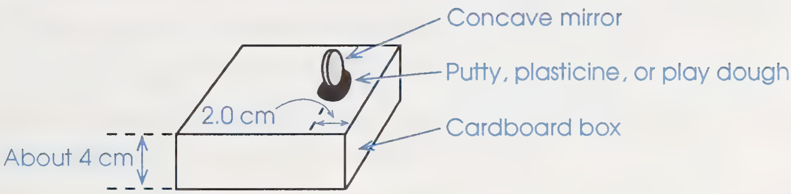
Materials

You will need the following materials for this investigation:

- convex mirror
- concave mirror
- metre stick or measuring tape
- candle
- plasticine, play dough, or putty to support mirrors
- a cardboard box that is 4 or 5 cm high (a tissue box is ideal)
- a small piece of cardboard (10 cm × 10 cm)
- screen (piece of white paper or white cardboard)
- a room with a window that can be made very dark
- a table
- masking tape

Procedure

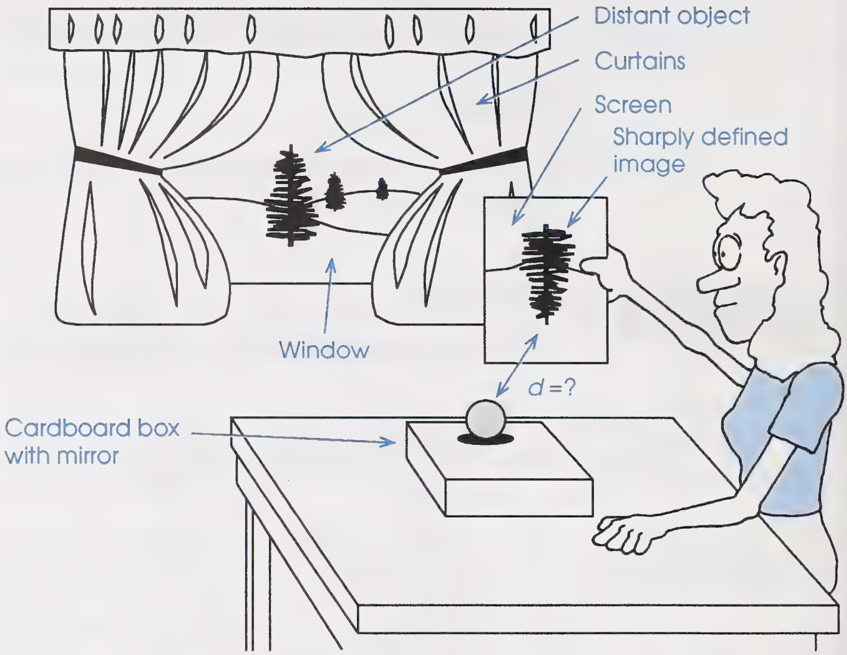
- Mount the concave mirror on the cardboard box with putty, as shown in the following diagram. Place the mirror 2.0 cm from the edge of the box.



Caution

When you handle mirrors, be sure to hold them by their edges and to be careful not to break them.

- Carefully place the box and the mirror on the side of the room opposite the window. Open the blind or curtains enough so that the room is still darkened, but so that light from a distant object outside the window can strike the mirror. Point the mirror at the distant object and then look for its image on the screen. The following diagram shows how to do this.



- If you are unable to locate an image, adjust the position of the box or the mirror. Sometimes the curtains need to be closed more to make the room darker. After these adjustments, you should find an image within 15 to 50 cm of the mirror.

5. Measure the distance between the image and the mirror. Remember that if you measure to the box, the mirror is 2.0 cm further. Record this value as the focal length in the diagram in the Observations section.

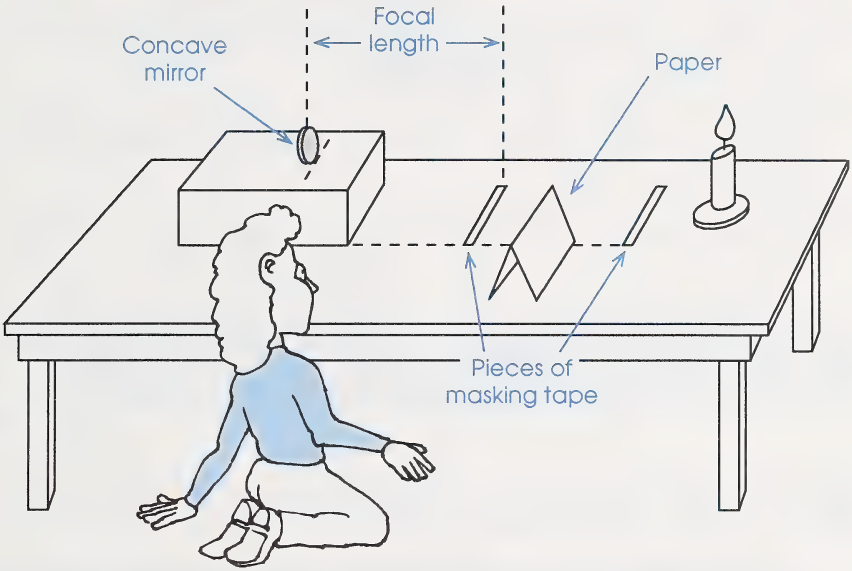
6. Calculate the radius of curvature and record this value in the diagram in the Observations section.

7. Predict the type of image that you would get if you repeated the procedure with the convex mirror.

8. Where would you have to look to find the image of the distant object with the convex mirror? Would you be able to use a screen?

9. Locate the image of the distant object created by the convex mirror. Describe what you see.

- For the remainder of the investigation, you will explore the properties of images in concave mirrors. You will use the candle flame as your object, rather than something outside the window. Arrange the apparatus as shown in the following diagram.



- Put a piece of masking tape at the locations of the focal point and the centre of curvature by using your earlier measurement of the focal length of the concave mirror. Just remember that the focal point is exactly one focal length from the mirror and that the centre of curvature is twice as far away from the mirror as the focal point.

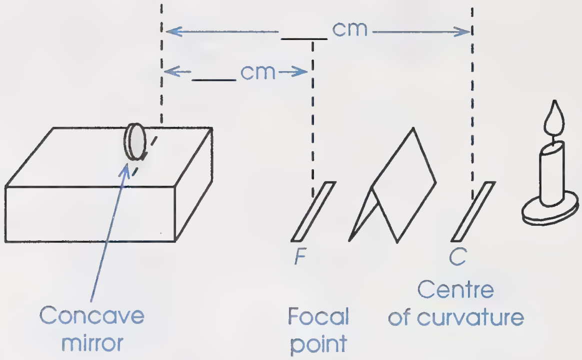
- Light the candle and attach it to a small piece of cardboard by securing it with melted wax. Stand the candle on the table. Darken the room as much as possible. Move the candle to a point beyond the centre of curvature and find the location of the screen that produces a sharply defined image of the object. This arrangement is shown in the previous diagram.

- Remember that a candle is an open flame. Care should be taken so that you do not start a fire or get burned.

10. Measure the distances between the candle and the mirror and between the screen and the mirror. Compare the size and orientation of the image on the screen with that of the actual candle. Record your measurements and observations on the data chart on the next page.

11. Move the candle to each of the other locations described on the data chart and find the location of the screen that produces a sharply defined image. In each case record the distances and the size and shape of the image on the chart. In one case no image will be formed. In another case the image will be virtual.

Observations



Data

Images Formed by a Concave Mirror				
Location of Candle	**Distance Between Mirror and Candle (cm)**	**Distance Between Mirror and Image (cm)**	**Size of Image Compared to Candle**	**Orientation of Image**
Beyond *C*				
At *C*				
Between *C* and *F*				
At *F*				
Between *F* and Mirror				

Conclusions

12. Where must the candle be located to create a real image in the concave mirror?

13. Where must the candle be located to create a virtual image in the concave mirror?

14. What location of the candle produces no image in the concave mirror?

15. Describe the fundamental differences between the virtual image created by a convex mirror and the virtual image created by a concave mirror.

16. Think about the convex security mirrors used in stores. Would concave mirrors be an acceptable alternative? Why or why not?

The images that you have seen with curved surfaces have been formed by the convergence of light rays. In the next activity you will locate those images using ray diagrams and equations.

Check your answers by turning to the Appendix, Section 1: Activity 2.

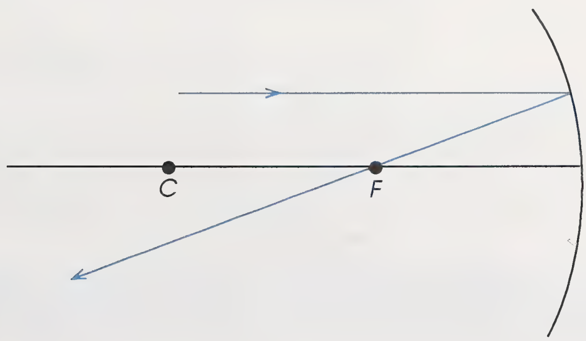
Activity 3: Equations for Curved Mirrors

You probably still have some questions regarding the images formed in curved mirrors. Why do the images appear at specific locations? Why are the images sometimes smaller or larger than the object? To fully understand these effects, you must understand some basic rules of reflection from curved surfaces. These rules are based on the law of reflection.

The rules for constructing ray diagrams for concave mirrors follow.

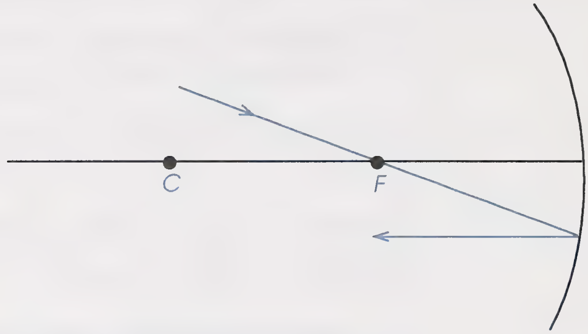
Rule 1

Rays that are parallel to the principal axis will reflect through the focal point.



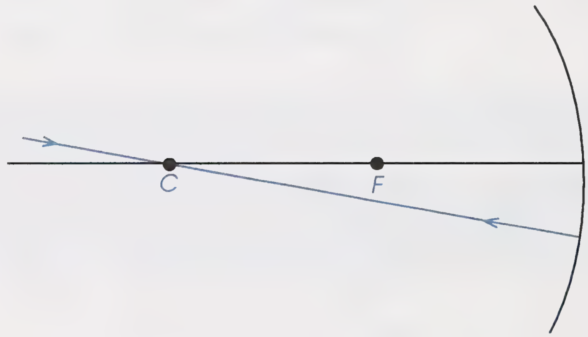
Rule 2

Rays that pass through the focal point will reflect parallel to the principal axis.



Rule 3

Rays that pass through the centre of curvature will reflect back along the same line.

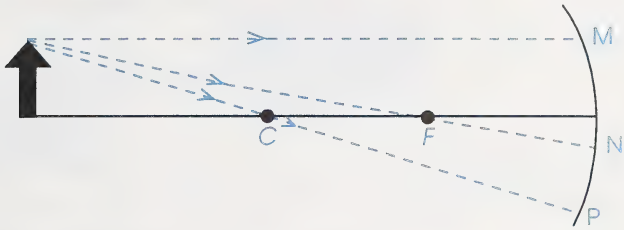


These rules are based on the law of reflection since the normal for each reflection will be a line that runs from the centre of curvature to the point of reflection on the mirror.

1. Explain why the normal runs from the centre of curvature to the point of reflection.

2. The preceeding sketches illustrate the rules of reflection from curved surfaces. Draw the normal on each sketch and verify the law of reflection by using a protractor. You may need to extend the rays to make accurate measurements.

3. a. Use the rules for constructing ray diagrams to sketch the reflected rays at points M, N, and P. The incident rays are indicated with dashed lines, so you should draw the reflected rays as solid lines.

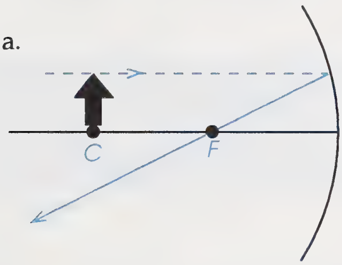


b. What do you notice about the three reflected rays?

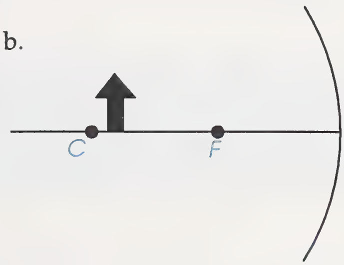
c. What will be found at the place where the three reflected rays intersect?

4. Locate the image of the solid arrow in each of the following diagrams. Use at least two of the three rules.

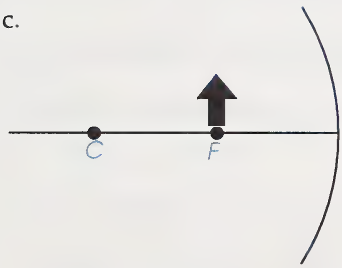
a.



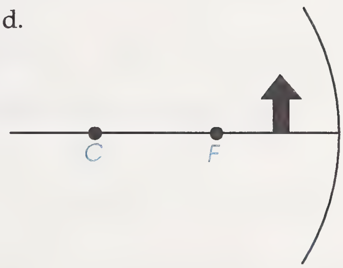
b.



c.



d.



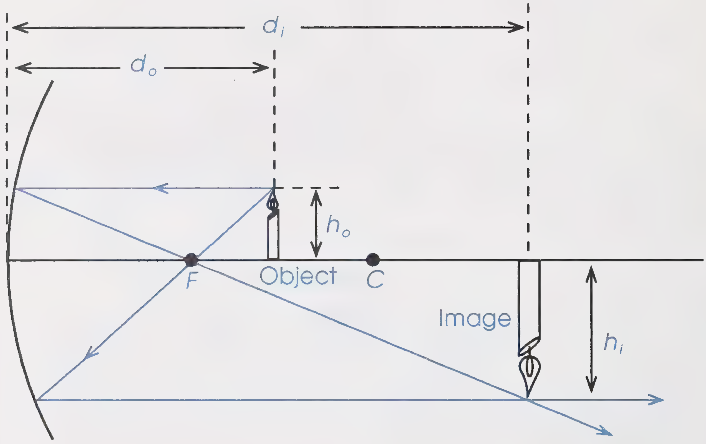
Compare your results from the previous question to the results from the investigation in Activity 2. Your results should be consistent with the theory. You should have noted that the virtual image created by the concave mirror is formed by the convergence of virtual rays rather than actual light rays.

Check your answers by turning to the Appendix, Section 1: Activity 3.

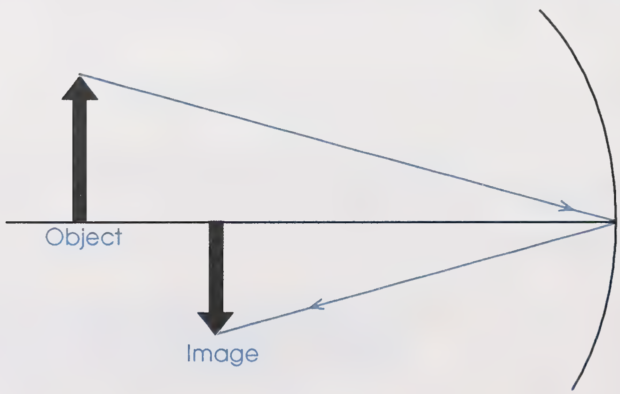
Magnification is defined as the ratio of the size of the image (h_i) to the size of the object (h_o). Through the use of some interesting geometry, you will see that this ratio is also equivalent to the distance between the object and the mirror (d_o) and the distance between the image and the mirror (d_i).

$$\boxed{m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}}$$

5. Suppose that a concave mirror created a 21.5-mm image of an 11-mm object. What would the magnification be in this case?



6. Use the following diagram, the law of reflection, and the definition of tangent to prove the magnification equation $\left(\frac{h_i}{h_o} = \frac{-d_i}{d_o}\right)$. Don't worry about the negative sign in the equation. This will be explained later.



The following equation relates the focal length (f), the distance to the object (d_o), and the distance to the image (d_i). This is called the **mirror equation**.

$$\boxed{\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}}$$

The derivation of this equation is also based on geometry, but it involves more steps and algebra. This derivation is explored in the Follow-up Activities for this section.

Read pages 373 and 374 of the textbook and examine the Example Problem on page 374. This Example Problem demonstrates the application of both the magnification equation and the mirror equation. Also note the explanations of the sign conventions.

7. Complete the following table that explains the circumstances for positive and negative values for the terms in the magnification and mirror equation.

Sign Conventions for Mirror and Magnification Equations					
	m	h_i	d_o	d_i	f
Positive Value					
Negative Value					

Many students find that the easiest way to remember the sign conventions is to memorize the following ideas.

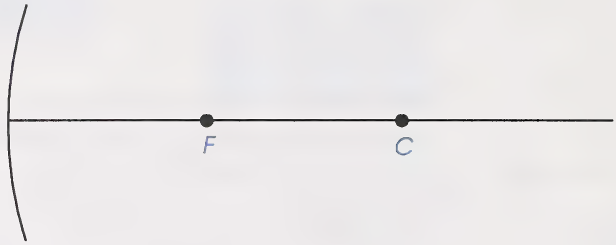
- If an image is below the principle axis, h_i and m are both negative.
- If either an image or a focal point is behind the reflecting side of the mirror, the value for d_i or f is negative.

8. What does a negative value of h_i and m represent?

9. In the Example Problem on page 374 of the textbook, the solution shows a transition from $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$ to $d_i = \frac{f d_o}{d_o - f}$. Show the intermediate steps in this transition.

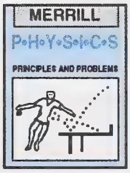
10. An object that is 8.0 mm high is 5.0 cm in front of a concave mirror with a focal length of 3.0 cm.

    a. Find the image by using a ray diagram. Use the following diagram for your sketch.



    b. Find the image by using the mirror equation.

    c. What is the height of the image?



11. Do Practice Problem 7 on page 376 of the textbook.

Check your answers by turning to the Appendix, Section 1: Activity 3.

12. Do Practice Problems 5, 6, and 8 on page 376 of your textbook.

Check your answers by turning to page 678 of your textbook.

The image formed by a concave mirror has several possible orientations, depending on the object's location. The convex mirror, on the other hand, is remarkably consistent from one location of the object to another.

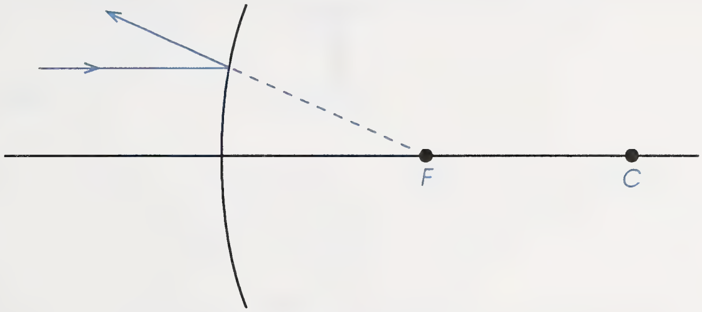
13. Without referring back to Activity 2, can you recall the relative size and location of the image of an object in any convex mirror?

Check your answers by turning to the Appendix, Section 1: Activity 3.

The rules for constructing ray diagrams for convex mirrors are very similar to those for constructing ray diagrams for concave mirrors. They are also based on the law of reflection.

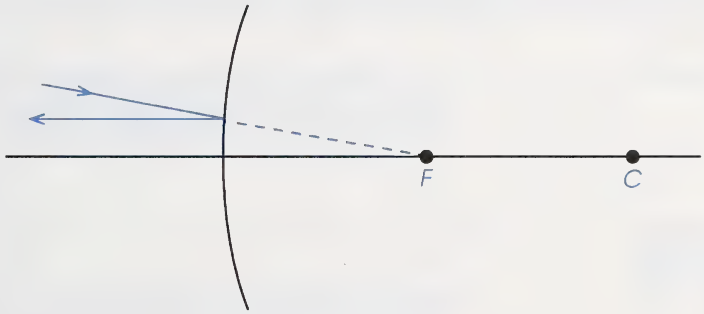
Rule 1

Rays that are parallel to the principal axis will reflect as if coming from the focal point behind the mirror.



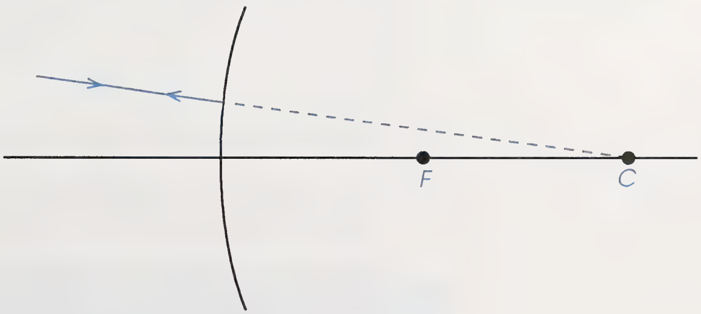
Rule 2

Rays that are headed for the focal point will reflect parallel to the principal axis.

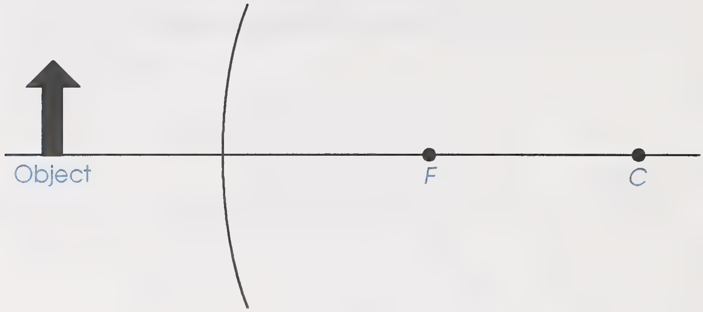


Rule 3

Rays that are headed towards the centre of curvature will reflect back along the same line.



14. Locate the position of the image by completing the following ray diagram.



The mirror equation and magnification equation also work with convex mirrors. It is worth your time to quickly review the meanings of negative values for f and d_i.

15. Calculate the magnification of the object in the Example Problem on page 377 of the textbook.

16. Do Practice Problem 10 on page 378 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 3.

17. Do Practice Problems 9 and 12 on pages 377 and 378 of your textbook.

Check your answers by turning to pages 678 and 679 in your textbook.

18. The convex sideview mirrors on trucks must conform to accepted standards. The radius of curvature must be between 890 mm and 1800 mm. A truck has a convex sideview mirror with a focal length of -78.0 cm.

    a. Does this mirror meet the necessary standards?

    b. A vehicle is located 60 m from the truck's mirror (behind the truck). Calculate the magnification of the vehicle.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

You began Section 1 by thinking about the convex mirrors in drugstores and then you continued by looking at concave mirrors. You examined both types of mirrors in the investigation in Activity 2. You then used ray diagrams and equations to locate and classify the images created.

1. Complete the following chart that will help you understand the types of images created and their relationship to the actual objects.

	Location of Object	Location of Image	Type of Image (Virtual/Real)	Size of Image (Smaller, Bigger, Same)
Concave	beyond *C*			
	at *C*			
	between *C* and *F*			
	at *F*			
	between *F* and *A*			
Convex	anywhere			

2. The sign convention is important when solving problems. What does it mean when you find a negative value for each of the following?

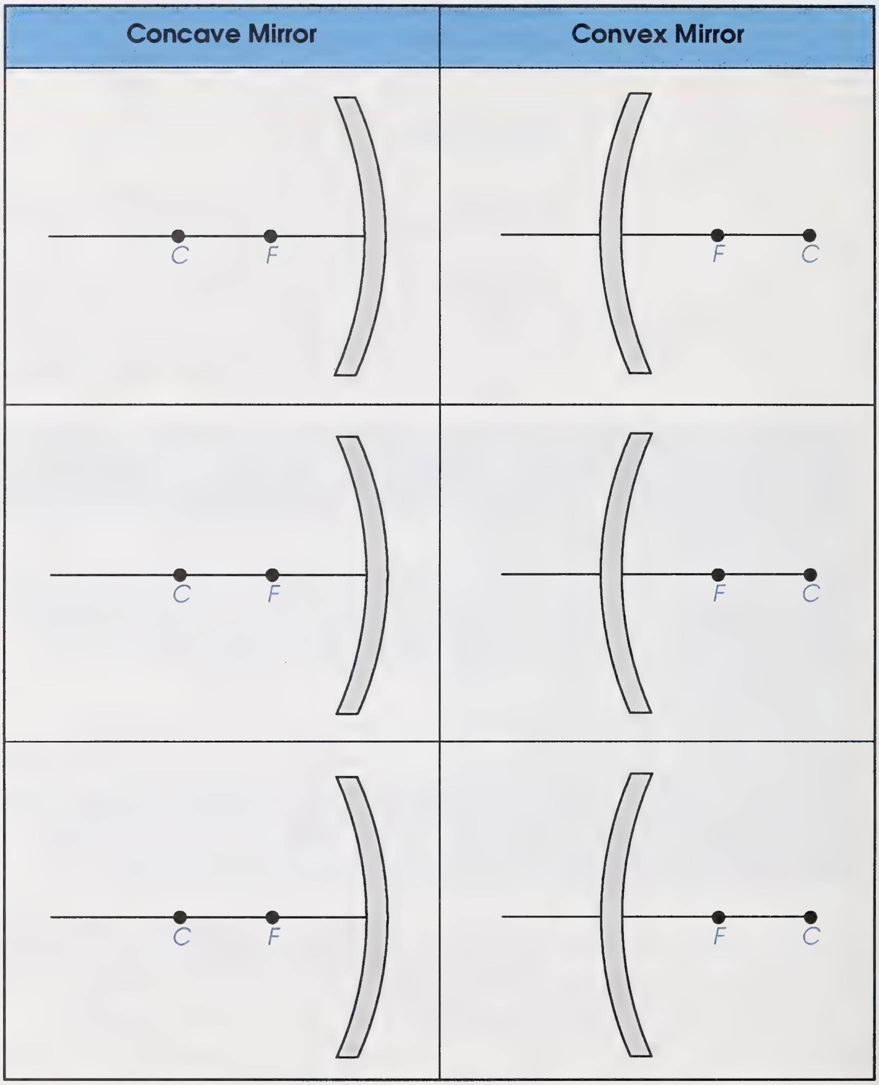
   a. d_i

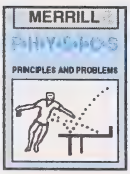
   b. h_i

   c. f

   d. m

3. You learned that the law of reflection provides the basis for the three rules for drawing ray diagrams for concave and convex mirrors. Illustrate these three rules by completing the following diagrams.





4. Do Practice Problem 3 on page 374 of the textbook. The equation and its rearrangement have been done for you.

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_o = \frac{f d_i}{d_i - f}$$

5. Do Practice Problem 11 on page 378 of the textbook.

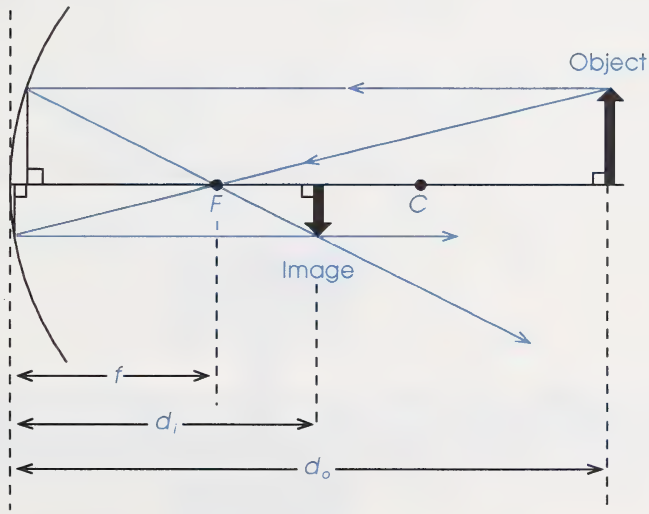
Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Choose **one** of the following activities.

1. Find an old headlight and carefully remove the lamp. Perform a simple test to determine the focal length of the reflector portion. Why is the filament of the lamp located at approximately the focal point?

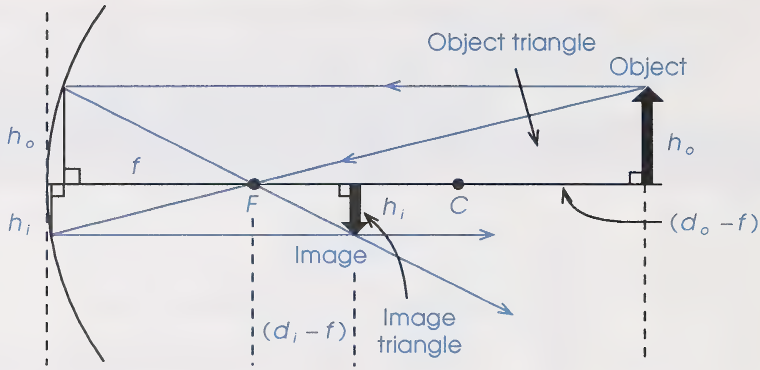
2. The derivation of the mirror equation requires much more manipulation than the derivation of the magnification formula. The derivation of the mirror equation is outlined on the following pages. Complete the derivation by filling in the missing steps.



Derivation of the Mirror Equation

Step 1: Identification of Triangles

The preceeding diagram shows how an image can be located for an object using ray construction. This diagram can be improved by labelling the sides of the similar triangles as follows.



Step 2: Applying Similar Triangles to the Previous Diagram

The object triangle is similar to the triangle that is located below the principal axis between the mirror and the focal point. Therefore, the sides of these two triangles are in the same ratio.

$$\frac{h_o}{(d_o - f)} = \frac{h_i}{f}$$

The image triangle is similar to the triangle that is located above the principal axis between the mirror and the focal point. Therefore, the sides of these two triangles are in the same ratio.

$$\frac{h_i}{(d_i - f)} = \frac{h_o}{f}$$

Step 3: Rearrange the Equations for Each Set of Triangles for $\frac{h_i}{h_o}$.

$$\boxed{\frac{h_o}{d_o - f} = \frac{h_i}{f}}$$

$$\downarrow$$

$$\boxed{\frac{h_o}{h_i} = \frac{d_o - f}{f}}$$

$$\downarrow$$

$$\boxed{\frac{h_i}{h_o} = \frac{f}{d_o - f}}$$

$$\boxed{\frac{h_i}{d_i - f} = \frac{h_o}{f}}$$

$$\downarrow$$

$$\boxed{\frac{h_i}{h_o} = \frac{d_i - f}{f}}$$

a. Complete Step 4.

Step 4: Combine the Equations to eliminate $\frac{h_i}{h_o}$.

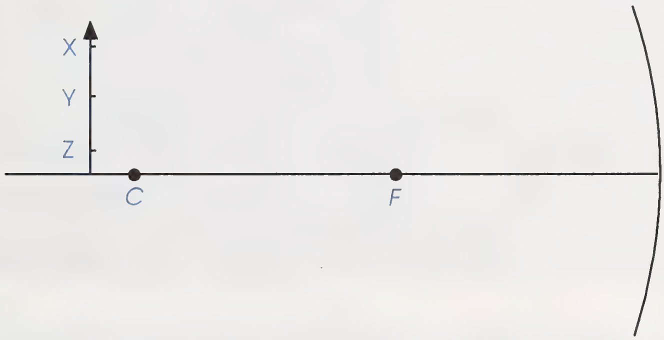
b. Complete Step 5.

Step 5: Rearrange Using Algebra to Obtain the Mirror Equation

c. The labelling of the triangles shows an approximation. Two of the triangles have a side that has an approximate value. Which two triangles have this approximation? Explain briefly.

d. Under what circumstances will this approximation be very close to the actual value? Explain briefly.

3. You have constructed several ray diagrams, but you usually located only the tip of the image. After that you assumed that the image would be vertical like the object. To prove that the image remains vertical, use the diagram below and locate the images of points X, Y, and Z. Use the rules that you have learned in this section.



Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

Module 6 introduced you to the law of reflection and to the formation of an image in a plane mirror. In this section of Module 7 you have extended these ideas to include convex and concave mirrors. You have seen that the images formed by curved mirrors included many possibilities that could be described by either ray diagrams or equations.

The next section will be developed in a similar fashion as you extend your knowledge of Snell's law to include lenses.

Assignment Booklet

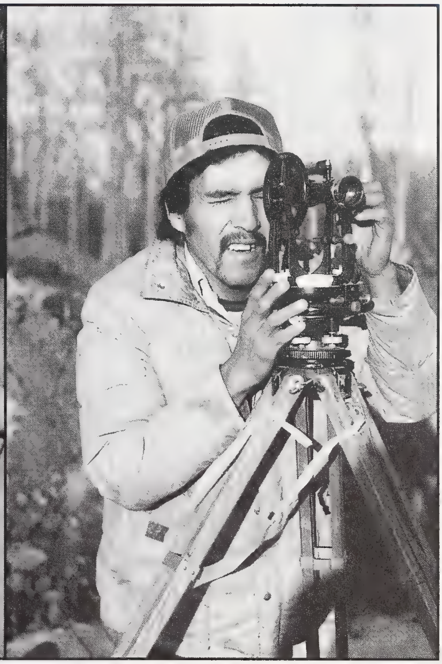
ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Lenses

WESTFILE INC.



WESTFILE INC.

What optical device do you rely on the most in your life? Think of all the high technology involved in cameras and video cameras. Also consider telescopes, microscopes, and binoculars. Despite all this technology, the device that you probably rely on the most is your eyes.

In this section you will learn about your eyes and how some of the common vision defects can be corrected with prescription eyeglasses. The main ideas that explain how your eyes work can be related to the basic principles of lenses.

You will begin the section with an introduction to lenses and then you will perform an investigation to explore the images that a lens can create. Finally, you will learn how to use equations to describe the images created by lenses.

Activity 1: Describing Images in Lenses

The equations and basic ideas of ray diagramming that you learned in the last section will also work in this section.

It's probably a good idea to begin this activity with an overview of the types of lenses and their properties. Read the two paragraphs on the bottom of page 378 of your textbook and then answer the questions that follow.

1. Describe what makes an object a lens.

2. Define the terms *convex lens* and *concave lens*.

3. Carefully examine Figure 18-14 on page 380 of your textbook. What type of lens is also called a diverging lens? What type is also called a converging lens?

4. What property of light allows lenses to change the direction of light rays?

Check your answers by turning to the Appendix, Section 2: Activity 1.

Now that you know what lenses are, it would be helpful to see some demonstrations of how they work.

PATHWAYS

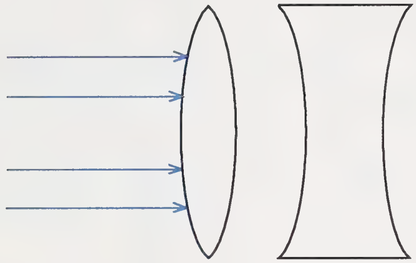
If you have access to the video entitled *Convex and Concave Lenses*, do Part A. If you do not have access to the video, do Part B.

Part A

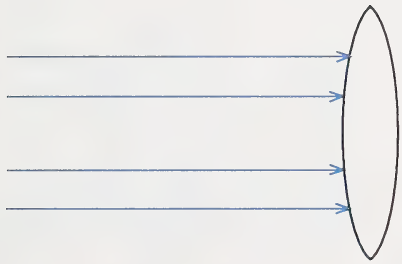
This video shows some interesting demonstrations that illustrate the properties of concave and convex lenses. Quickly read through the questions before watching the video. You may need to stop the tape periodically to record your answers.

5. The following diagrams show light rays about to strike the water tank lenses. Complete the diagrams by drawing the path of the light rays passing through each lens and then travelling through the air on the other side.

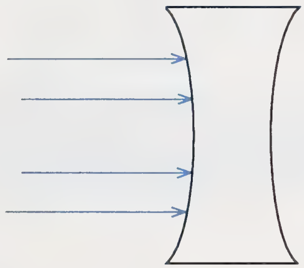
a.



b.



c.

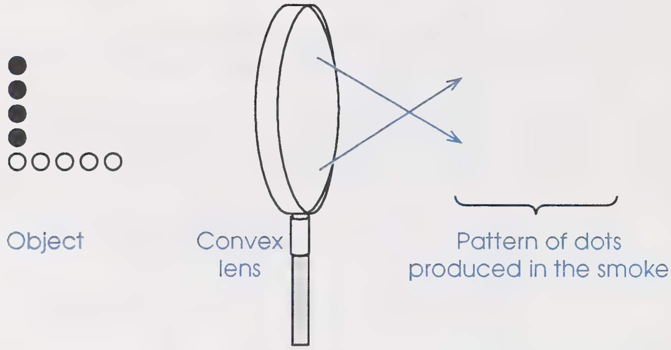


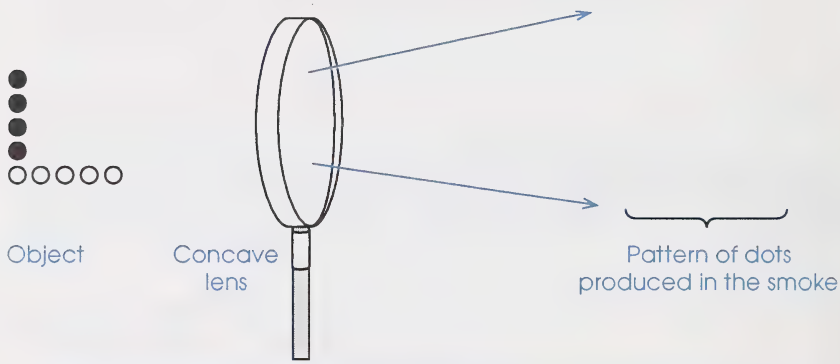
6. Label each of the lenses in the previous diagram either **convex** or **concave**.

7. Label each of the lenses in the previous diagram either **converging** or **diverging**.

8. Do the rays of light travel at the same speed through the air as they do through the lens? Concisely explain the speed changes of the light rays as they enter and leave the lens.

9. Complete the following diagrams by drawing in the missing light rays and showing the pattern of dots produced.

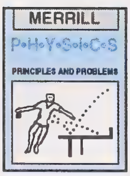




Check your answers by turning to the Appendix, Section 2: Activity 1.

End of Part A

Part B

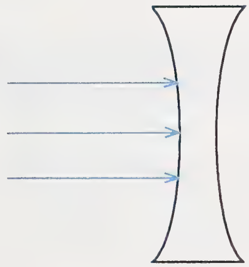


To help get a sense of how light behaves when it passes through lenses, you will survey the ray diagrams presented on pages 380 to 383 of your textbook.

10. Refer to Figure 18-14 on page 380 of your textbook. Complete the diagram of this figure by drawing in the missing light rays.

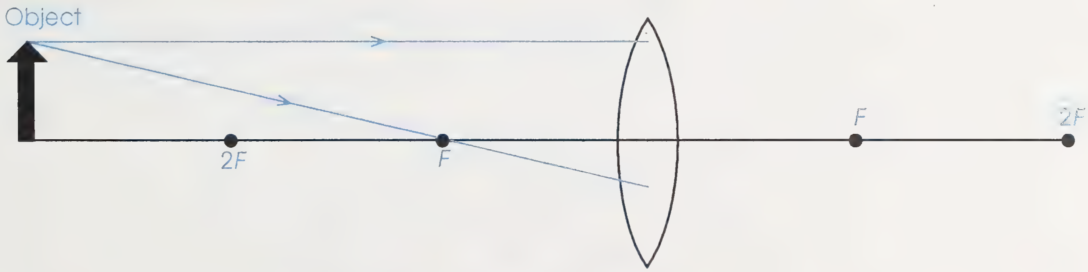
a.

b.



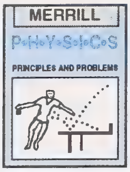
11. Label each of the lenses in the previous diagram either **convex** or **concave**.

12. a. Refer to Figure 18-16 on page 381 of your textbook. Complete the diagram of this figure by drawing in the missing light rays.

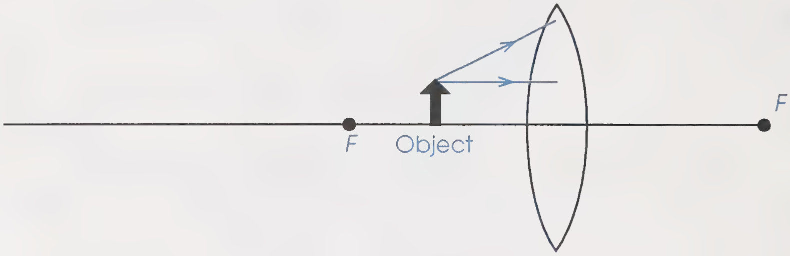


b. Add the image to the previous diagram.

c. Is the image that you added to the diagram real or virtual? Explain.

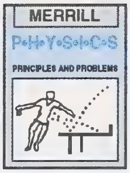


13. Refer to Figure 18-17 on page 382 of your textbook. Complete the diagram of the figure by drawing in the missing light rays. Draw the real light rays as solid lines and the virtual rays as dashed lines.

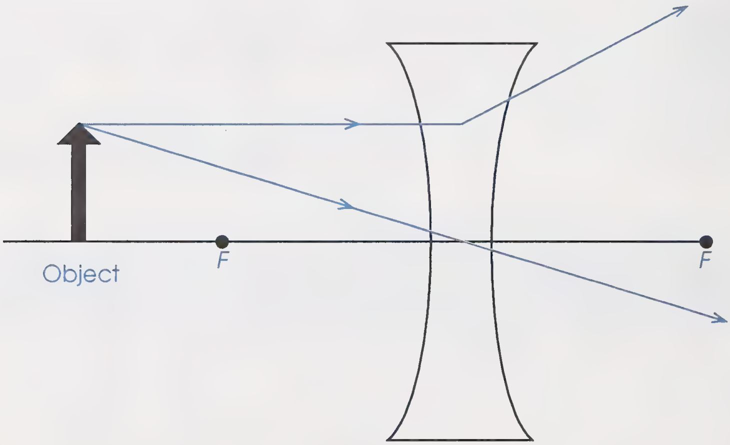


14. a. Add the image to the previous diagram.

    b. Is the image that you added to the diagram real or virtual? Explain.



15. Refer to Figure 18-18 on page 383 of your textbook. Complete the diagram of the figure by drawing in the missing light rays. Draw the real light rays as solid lines and the virtual rays as dashed lines.



16. a. Add the image to the previous diagram.

    b. Is the image that you added real or virtual? Explain.

Check your answers by turning to the Appendix, Section 2: Activity 1.

End of Part B

You probably noticed how similar ideas apply to both the ray diagrams for lenses and the ray diagrams for curved mirrors. The important difference between these two phenomena is that lenses operate on the principle of refraction, while mirrors work due to reflection.

Activity 2: Finding Images in Lenses

Now that you have a sense of how light behaves when travelling through convex and concave lenses, you should be able to complete the next investigation.

Investigation: Images Formed by Lenses

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Purpose

In this investigation you will discover the characteristics of images formed by convex and concave lenses.

Materials

You will need the following materials for this investigation:

- convex lens
- concave lens
- metre stick or measuring tape
- candle
- play dough or putty to support the lenses
- a cardboard box that is 4 or 5 cm high (a tissue box is ideal)
- a small piece of cardboard (10 cm $\times$ 10 cm)
- screen (piece of white paper or cardboard)
- a room with a window that can be made very dark
- a table
- masking tape

Procedure

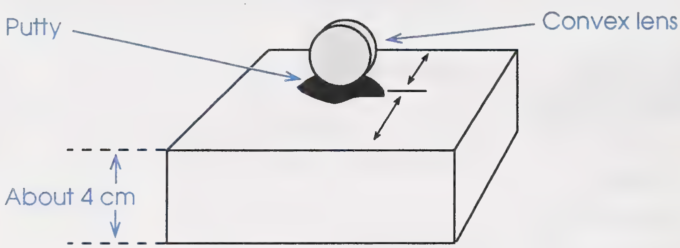
1. Hold the concave lens in one hand while looking out the window at a distant object. Position the lens at arm's length and look at the distant object through the lens. Record the image that you see in the diagram in the Observations section.

2. Slowly move the lens closer to your eye and note any changes in the image of the distant object. Describe how the image changed as you brought the lens closer to your eye.

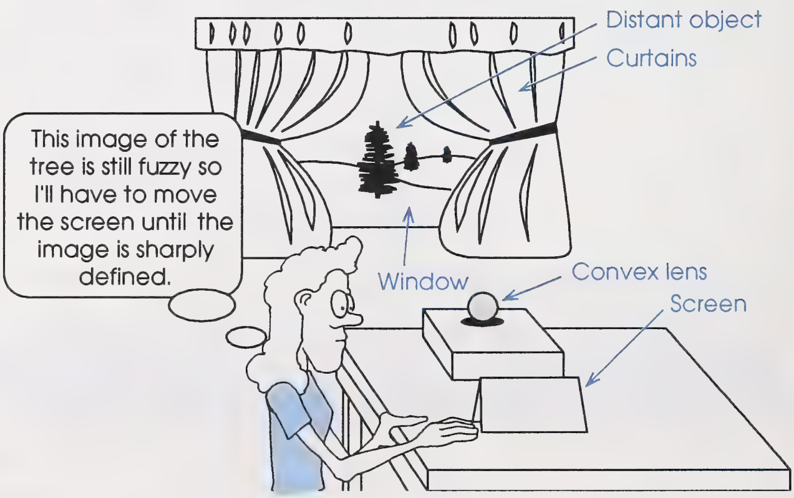
3. Repeat the procedure with the convex lens. Record the image of the distant object in the diagram in the Observations section.

4. Describe how the image changed as you brought the convex lens closer to your eye.

- For the remainder of this investigation, you will use the convex lens and screen to locate the positions of images. Mount the convex lens on the cardboard box with the putty, as shown in the following diagram. Note that the lens is in the middle of the box and is facing the nearest edges. Be sure to hold the lens by the edges when you handle it.



- Carefully place the box and the lens on the side of the room opposite the window. Open the blinds or curtains so that the room is still darkened, but light from a distant object outside the window can strike the lens. Point the lens at the object and then look for its image on the screen. The following diagram shows how to do this.

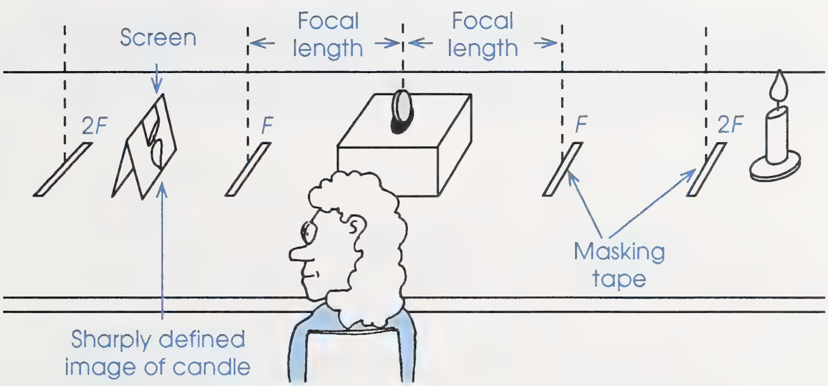


- If you are unable to locate an image, adjust the position of the box or the lens. Sometimes the curtains need to be closed more to make the room darker. After these adjustments, you should find the image within 15 to 50 cm of the lens.

5. Measure the distance between the image and the mirror. Record this value in the diagram in the Observations section as the focal length (*F*).

6. Calculate the value of twice the focal length (2*F*) and record this value in the diagram in the Observations section.

- Arrange the apparatus as shown in the following diagram.



- You will need to put pieces of masking tape at the locations of *F* and 2*F*. *F* is exactly one focal length from the mirror and 2*F* is twice as far from the mirror.

- Light the candle and secure it to the small piece of cardboard with melted wax. Darken the room as much as possible. Move the candle to a point beyond 2*F* and find the location of the screen that produces a sharply defined image of the candle.

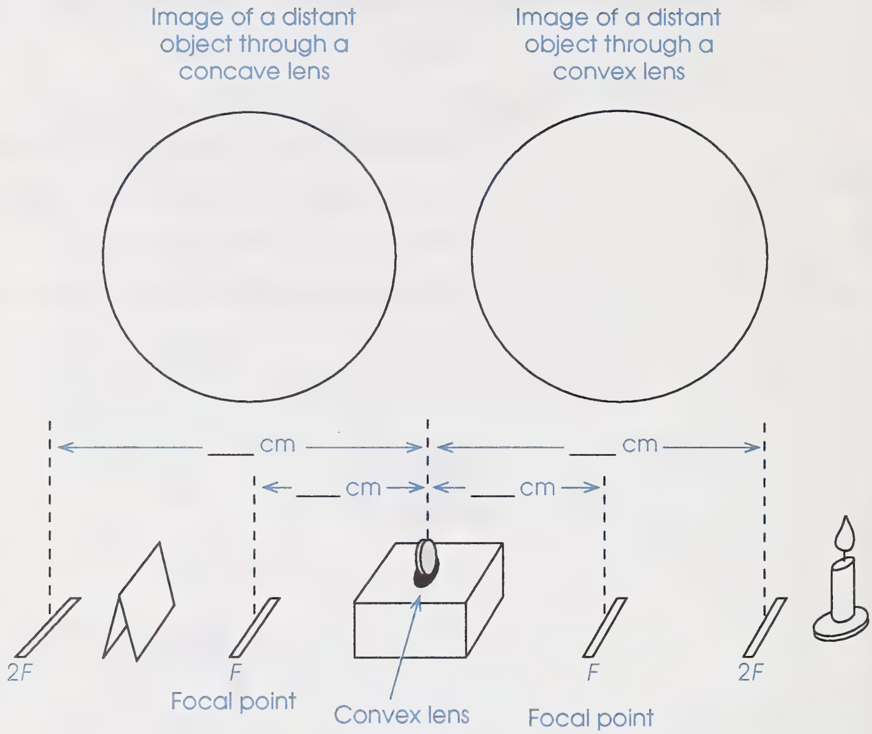
Caution

- Remember that a candle is an open flame. Care should be taken so that you do not start a fire or get burned.

7. Record the distance between the candle and the lens and between the screen and the lens. Record the size and orientation of the image on the screen compared to that of the actual candle. Record your measurements and observations on the data chart.

8. Move the candle to each of the other locations described on the data chart and find the location of the screen that produces a sharply defined image. In each case record the distance, the size, and the orientation of the image on the chart. In one case no image will be formed. In another case the image will be virtual.

Observations



Data

Images Formed by a Convex Lens				
Location of Candle	**Distance Between Lens and Candle (cm)**	**Distance Between Lens and Screen (cm)**	**Size of Image Compared to Candle**	**Orientation of Image**
Beyond 2*F*				
At 2*F*				
Between *F* and 2*F*				
At *F*				
Between *F* and Mirror				

Conclusions

9. Where must the candle be located in order to create a real image in a convex lens?

10. Where must the candle be located in order to create a virtual image in a convex lens?

11. What location of the candle produces no image in a convex lens?

12. Describe the differences between the virtual image created by a convex lens and the virtual image created by a concave lens.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Ray Diagrams for Lenses

Many of the ideas developed for dealing with curved mirrors apply to the study of lenses. You have probably noticed the similarities between the data chart for lenses and the one for curved mirrors in the previous section.

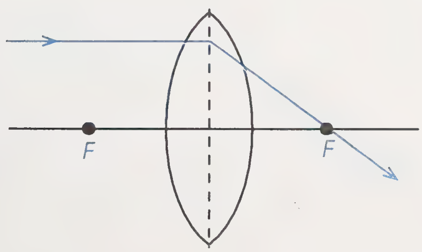
These similarities also apply to the rules for ray diagrams for lenses. As you examine the following diagrams, look for the same trends that you established in the previous section.

Ray Diagrams for Convex Lenses

Note: You will notice that the drawings here and in the textbook show refraction occurring only once in the middle of the lens. This is strictly for ease of sketching and is not truly accurate, as refraction occurs at both boundaries.

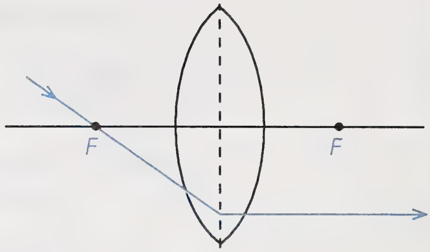
Rule 1

Rays that are parallel to the principal axis will refract through the focal point.



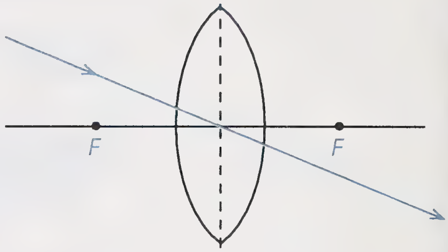
Rule 2

Rays passing through the focal point on one side will refract parallel to the principal axis.



Rule 3

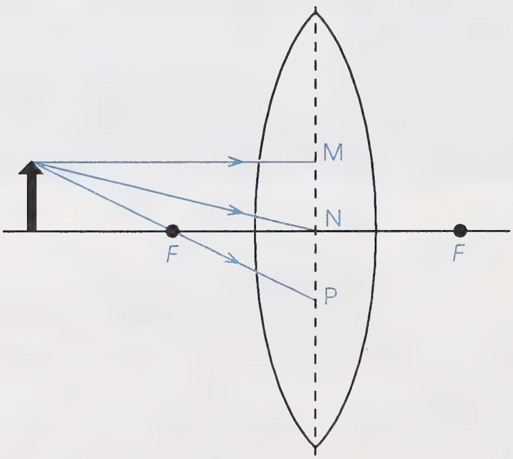
Rays that are headed towards the centre of the lens will pass through with very little deflection. This rule is an approximation and is not totally accurate. It is true that the refracted ray is parallel to the incident ray, but the refracted ray is shifted slightly.



13. Adjust the previous sketch (Rule 3) to show how the light actually refracts through the lens at the centre.

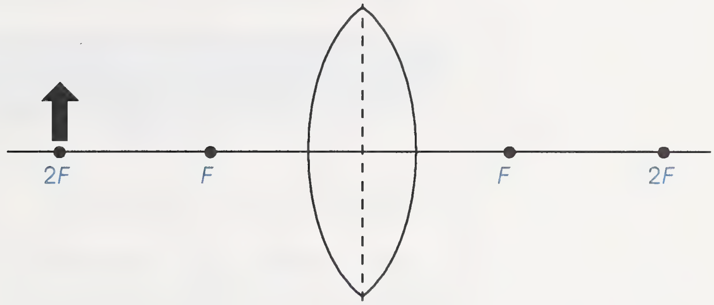
Although the rules are approximations, if the lens is thin, the ray diagrams can provide good predictions of image location.

14. Use the rules for drawing ray diagrams to sketch the refracted rays at points M, N, and P.

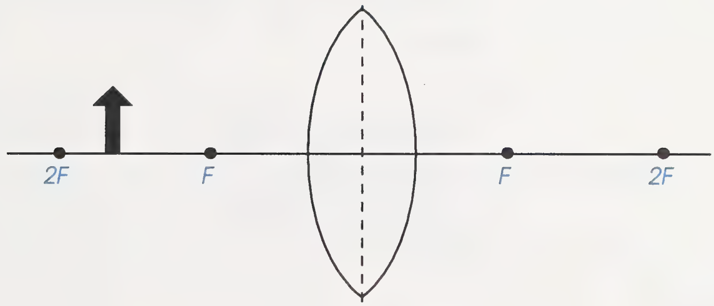


15. Locate the image of the solid arrow in each of the following diagrams. Use at least two of the rules for ray diagrams. Remember to draw solid lines for the real rays and dashed lines for the virtual rays.

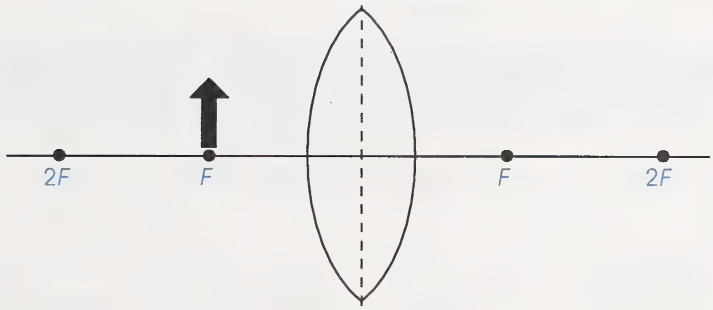
a.



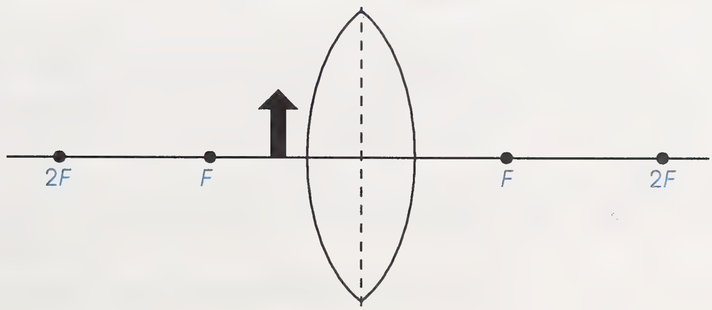
b.



c.



d.



16. Compare the results of your ray diagrams in the previous question with those that you drew for the investigation that you did at the start of this activity. Are the observations confirmed by these ray diagrams? Are the sizes of the images what you expected?

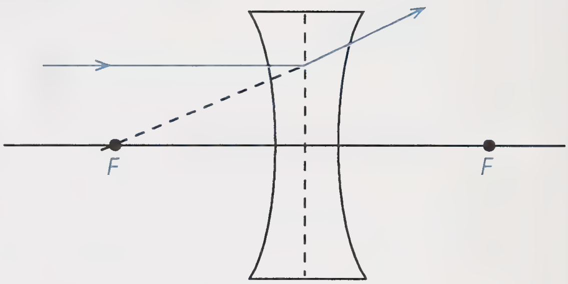
Check your answers by turning to the Appendix, Section 2: Activity 2.

Ray Diagrams for Concave Lenses

You have discovered that concave lenses always produce smaller virtual images. To test this observation, you can use three rules. The rules for constructing ray diagrams for concave lenses follow.

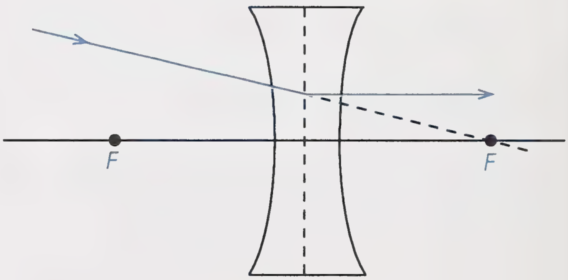
Rule 1

Rays that are parallel to the principal axis will refract as if coming from the focal point on the object's side of the lens.



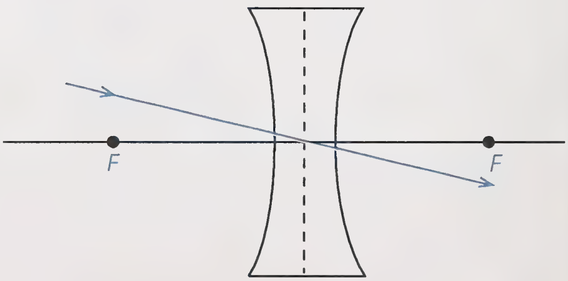
Rule 2

Rays that are headed for the focal point on the other side of the lens will refract parallel to the principal axis.



Rule 3

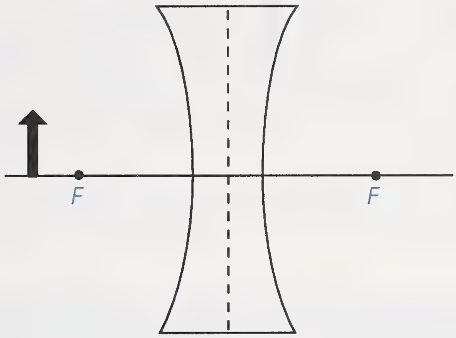
Rays that are headed for the centre of the lens will pass through with very little deflection.



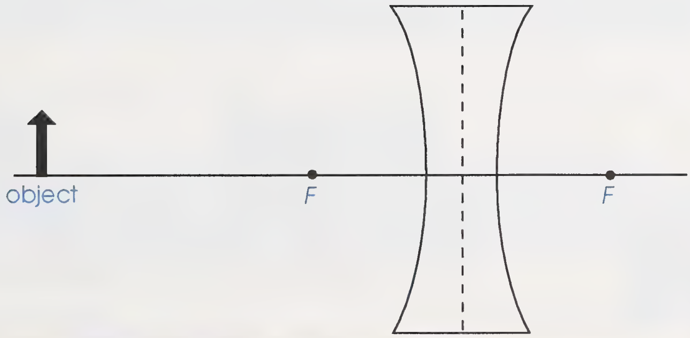
Once again, these approximations apply only for thin lenses.

17. Demonstrate that a smaller virtual image is created for both of the lenses shown. Use all three rules in each case.

a.



b.



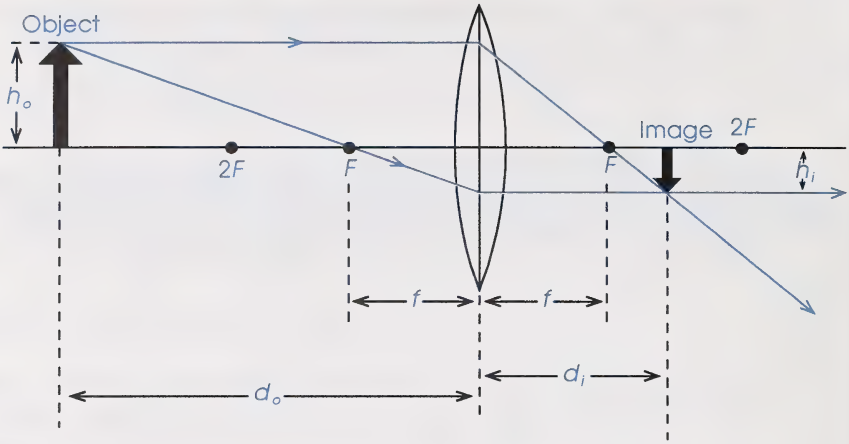
Check your answers by turning to the Appendix, Section 2: Activity 2.

You will look at the algebraic approach to lenses in the next activity.

Activity 3: Applications of Lenses

In the last activity you discovered that the data collected for images from lenses had many similarities to the data collected for curved mirrors. This was also the case for the rules for drawing ray diagrams. If the ray diagrams and data are similar, the geometry and equations should also be similar.

The equations for lenses are identical to those developed for curved mirrors. Only the names and some of the interpretations of positive and negative signs are different.



Magnification Equation

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

Lens Equation

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

MERRILL PHYSICS PRINCIPLES AND PROBLEMS

Read pages 380 to 382 in your textbook to confirm your understanding of these equations and to learn the sign conventions used for the variables.

1. Complete the table that follows by explaining the circumstances for negative and positive values for the terms in the magnification and lens equations.

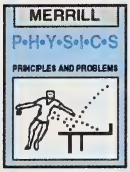
Sign Conventions for Equations Applied to Lenses

	m	h_i	d_o	d_i	f
Positive Value					
Negative Value					

2. Compare the previous answer to the chart that you completed in Activity 3 of Section 1. Which columns are different?

Students find that the easiest way to keep all this information straight is to memorize the main ideas.

- If an image is below the principal axis, h_i and m are both negative.
- If either an image or focal point is on the same side of the lens as the object, the value for d_i or f is negative.



3. Examine the Example Problems on pages 381 and 382 in the textbook. Are the answers to these problems consistent with the main ideas just listed?

Check your answers by turning to the Appendix, Section 2: Activity 3.

4. Do Practice Problems 14 to 20 on pages 381 and 383 in the textbook.

Check your answers by turning to page 679 in your textbook.

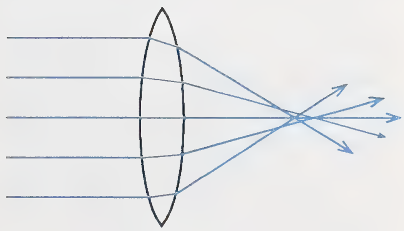
Lens Aberrations

It is important to remember that the equations and ray diagram rules are approximations based on an ideal thin lens. An ideal thin lens would be impossible to manufacture because it must be infinitely thin compared to its diameter. Actual lenses that are built for use in instruments such as eyeglasses or microscopes are not perfect and their actual behaviours deviate from the simple theories for thin lenses. These deviations are called **lens aberrations**.

lens aberrations – deviations in the behaviour of light passing through an actual lens. The behaviour of light that is predicted by ray diagrams occurs only in ideal, thin lenses.

spherical aberration – the effect of parallel light rays at the edges of a curved mirror or lens reflecting or refracting to different focal points

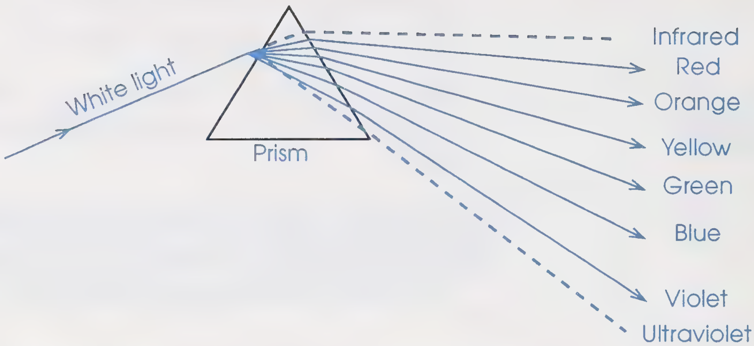
One aberration is due to the way that lenses are manufactured. The most cost-effective way to make a lens is to make the shape of its outer surface spherical. However, a spherical shape will not bring parallel light rays to a single point. The result of this **spherical aberration** is that the light gathers in a conical patch, as shown in the diagram.



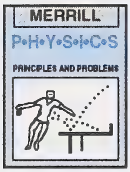
5. Can you think of a simple method for eliminating spherical aberration?

chromatic aberration – the effect of colours refracting at different angles and having different focal points

Chromatic aberration relates to the fact that the different colours of light each have a different index of refraction. You were introduced to this idea when you studied the dispersion of light by a prism in Module 6.



You may recall from Module 6 that the whole study of colour began when Isaac Newton first noticed that the white light entering his telescope produced colours at the focus. You could say that chromatic aberration triggered the study of colour.



Read the section called Chromatic Aberration on pages 383 and 384 of your textbook.

6. How is the problem of chromatic aberration solved? Make a sketch to assist your explanation.

7. Why is there chromatic aberration in a lens, but not in the light that reflects from a curved mirror?

Check your answers by turning to the Appendix, Section 2: Activity 3.

compound lens system – uses more than one lens

The use of **compound lens systems** reduces the effects of aberrations. This is why most optical instruments use a system of two or more lenses.

The Human Eye

The most sophisticated optical system available to humans is one that you already possess – your eyes. The human eye is a remarkable device. It contains a built-in cleaning and lubricating system, an automatic focus, and a light meter. A camera with those features would be considered high technology.

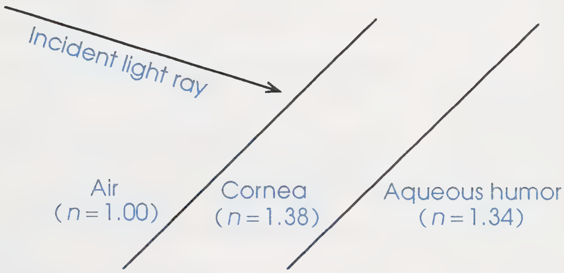
MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

To learn about the basic parts of the eye and how they work together as a system, read the middle paragraph on page 384 of your textbook. Be sure to refer to Figure 18-20 on the bottom of the page as you learn the names for the parts of the eye.

8. A ray of light travels from the air (n = 1.00) to the cornea (n = 1.38) and then through the aqueous humor (n = 1.34) and the lens (n = 1.44).

   a. Between which two media does the light ray experience the most refraction? How do you know?

   b. A small section of the cornea is shown on the following diagram. A light ray is incident on the first boundary (air/cornea). Measure the angle of incidence in the air using a protractor and label it on the following diagram.



   c. Calculate the angle of refraction in the cornea.

The eye will automatically focus on objects that are near or far away and the image of the object will be clearly displayed on the retina at the back of the eye. The most sensitive region of the retina is the fovea. Your eyes will rotate so that the object under examination is imaged on the fovea.

near point – the closest distance for which the lens of the eye can create a sharp image on the retina

The **near point** changes with age, but the average near point is about 25 cm. The chart shows how the near point changes with age.

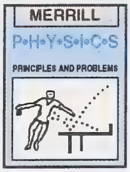
Age (years)	Near Point (cm)
10	7
20	10
30	14
40	22
50	40
60	200

To find your near point, put a book or printed page out in front of you and slowly bring it towards your face. When the image becomes blurry, you have reached the near point.

9. The retina is approximately 2.5 cm behind the lens. Assuming that the near point is 25 cm and the lens will focus on objects at extremely long distances, what is the range of focal lengths to which the lens can adjust?

accommodation – the ability of the lens in the eye to adjust its focal length through the action of the ciliary muscles

This ability of the lens to adjust its focal length is called **accommodation**. It does this by relaxing and contracting the ciliary muscles that hold the lens. When the muscles contract, they cause the lens to assume a more spherical shape and the resulting focal length decreases.



10. You are focusing on an object that is 2.0 m away. You then turn and focus on an object that is only 1.0 m away. Must the ciliary muscles relax or contract in order to focus on the nearest object? Explain.

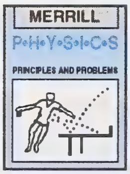
Defects of Vision

myopia – nearsightedness; the focal length of the eye is too short, causing objects at a distance to be blurred

There are a number of common problems associated with the focusing capabilities of the eye. For a brief discussion of the three most common defects, read the second paragraph of the section titled Optical Instruments on pages 384 and 385 of the textbook.

hyperopia – farsightedness; the focal length of the eye is too long, causing nearby objects to be blurred

11. For either **myopic** or **hyperopic** eyes, the defect is in the range of accommodation of the lens. Discuss the specific problem for each of the two defects and draw diagrams to support your answer.



Examine Figures 18-17 and 18-18 on pages 382 and 383 of the textbook.

Myopic (nearsighted) eyes require concave lenses because the lenses will take distant objects and form virtual images that are closer, as shown in Figure 18-18. If you are nearsighted, take a close look at your eyeglasses. Although the outer part of the lens makes it appear convex, the thicker part of the lens is towards the edge, which means it is definitely concave.

The hyperopic (farsighted) eye requires a convex lens that will take close objects and form virtual images that appear further away, as shown in Figure 18-17.

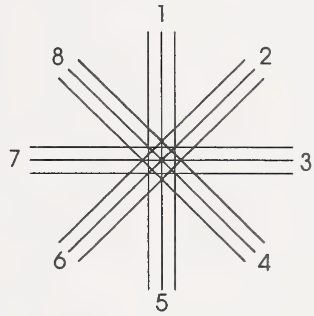
As described by the textbook, the corrective lenses could be provided by eyeglasses or by contact lenses. It is interesting to note that a unique feature of the cells in the cornea imposes a limit on the length of time that a person can wear contact lenses. While most cells in the body receive oxygen from blood carried by blood vessels, the cells of the cornea receive oxygen from the air outside the eye. The oxygen from the air diffuses through the tear fluid to the cornea.

12. Why aren't there any blood vessels in the cornea?

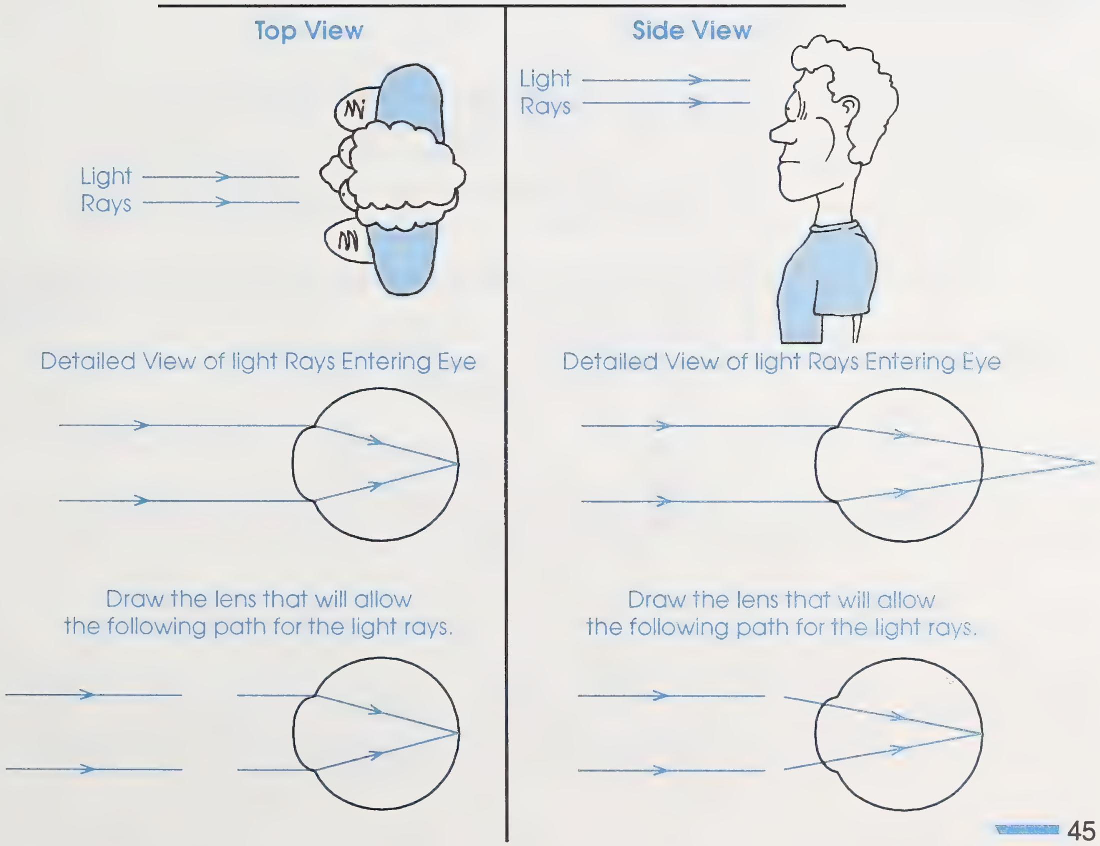
13. Explain why there is a limit on the number of consecutive hours that a person can wear contact lenses.

astigmatism – a defect present in an eye that will not focus sharply in all planes

Astigmatism is the third defect that you read about. The diagram shown is a common test for astigmatism. Optometrists will note which lines are most clear and which are less defined for your eyes. With the results of such a test, the optometrist can prescribe appropriate lenses.



14. a. The diagrams that follow show the top view and the side view of an eye. There are two parallel rays coming into the eye in each case, but due to an astigmatism, the eye does not react the same in each case. Complete the chart by drawing the appropriately shaped lens in each column.



b. Combine your two ideas from the chart in order to sketch a three-dimensional lens that will solve this person's astigmatism.

Hint: Make the lens square, rather than round.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Now that you've seen how the basic physics of lenses can be applied to your eyes, you should have a new appreciation for your eyes as an optical system.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

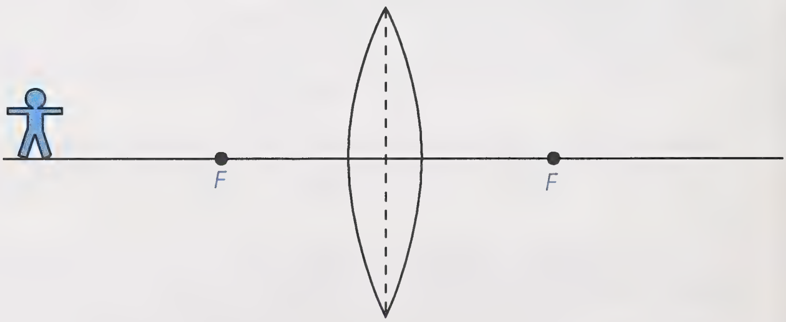
Extra Help

1. a. Concave mirrors and convex lenses treat light rays in a similar manner. Explain the similarities. Draw a diagram to help explain.

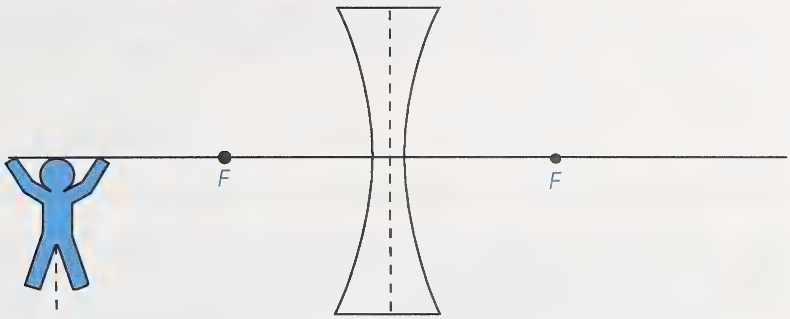
   b. Explain the similarity between convex mirrors and concave lenses. Draw a diagram.

2. Use ray diagrams to locate the image of the stick person in each of the following sketches.

   a.



b.



3. Use a ruler to measure the proper values in 2. a. Check the validity of the magnification equation $\left(\frac{h_i}{h_o} = \frac{-d_i}{d_o}\right)$.

4. Do Supplemental Problem 14 on page 701 of the textbook.

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do **one** of the following activities

1. Problem-solving

   a. Do Concept Review question 2.4 on page 386 of the textbook.

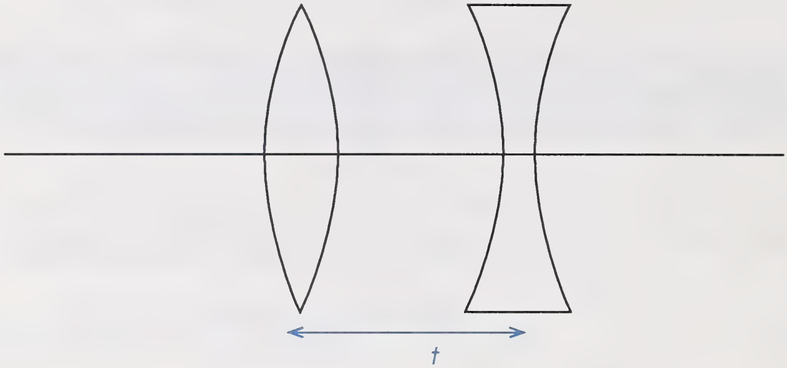
   b. A convex lens in a photocopier has a focal length of 22.0 cm. It is set to enlarge an original by 200 percent. Where are the image and original located relative to the lens?

2. Compound Lens System

   When two lenses are used in combination, the resulting focal length (f) can be found by using the following equation.

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{t}{f_1 f_2}$$

In this equation f_1 and f_2 are the focal lengths of each of the lenses and t is the distance between their centres, as shown in the following diagram.



a. A convex lens ($f = 20$ cm) is placed 10 cm from a concave lens ($f = -20$ cm). Find the resulting focal length.

b. Two lenses are to be placed in contact to form a compound lens with a focal length of 8.0 cm. One of the lenses is a convex lens with a focal length of 12.0 cm. What other lens must be used?

3. The Telescope

If you have access to the enrichment booklet which accompanies the teacher resource package for your textbook, do the exercise for Chapter 18 entitled The Telescope.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you have learned how to create ray diagrams and use equations to locate the images produced by lenses. As well, you have taken a glimpse at the human eye and have learned that it is a system of lenses.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

Section

3 Interference of Light

A customer was told by a salesperson that one model of CD player was better than another because it used a three-beam laser. The customer inquired if that meant that the CD player actually had three lasers.

A CD player with three beams actually only has one laser. The single beam of laser light is split into three parts using the properties of diffraction and interference of light.

In this module you will learn about the first experiments that explored the diffraction and interference of light. You will then investigate the equation that is used to describe the interference of light. Finally, you will apply these ideas as you complete an investigation to determine the wavelength of light.

Activity 1: Young's the One

There is a connection between the topics of interference and diffraction and your work with lenses and the human eye.

Thomas Young was an exceptionally talented English physician and physicist. His interest in the study of light began while he was studying the eye as a medical student. It was at this time that he discovered how the eye changes shape in order to focus objects that are up close and those that are far away. Within three years of beginning his medical practice in London, he discovered that irregularities in the cornea caused astigmatism.

Young's interests soon shifted to the study of light itself. At this time in history, the controversy about whether light was a particle or a wave had been debated for over one hundred years. The supporters of the particle theory thought that if light had a wave nature, it should be able to diffract around objects and form beats the way that sound waves did. It was up to Thomas Young to experimentally prove that light could do this.

Thomas Young

In 1803 Young showed that light diffracted when it was passed through a narrow slit. Later he showed that when light passed through two narrow openings, the light spread out and overlapped, creating an interference pattern. Young used these results to calculate a value for the wavelength of light. He determined the wavelength of light to be less than one millionth of a metre.

Unfortunately, Young's discoveries were met with hostility by many members of the scientific community in England at the time. Since Isaac Newton had favoured the particle model, many physicists of that time were very hesitant to support a different explanation. However, eventually two French physicists, Fresnel and Arago, did the necessary follow-up work and by 1850 the wave model of light was generally accepted.

Young's Experiment

Young's experiment is worth looking at not only because of its historical significance, but also because it allows you to apply important ideas about the diffraction and interference of waves from Module 5 to your current study of light.

PATHWAYS

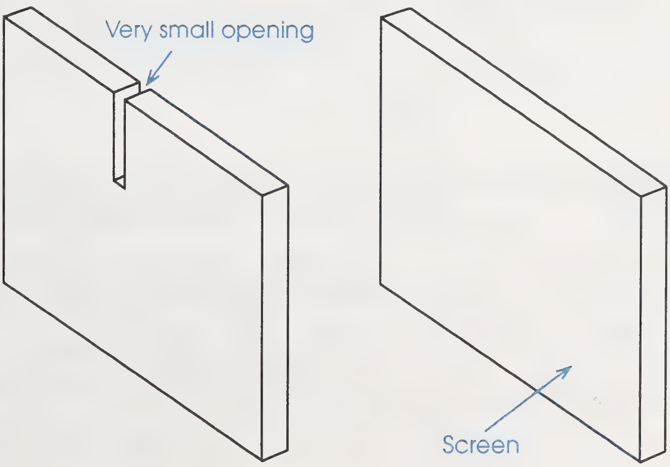
If you have access to the video entitled *The Wave Model*, which is the second program from the video series called *Wave-Particle Duality*, do Part A. If you do not have access to this video, then do Part B.

Part A

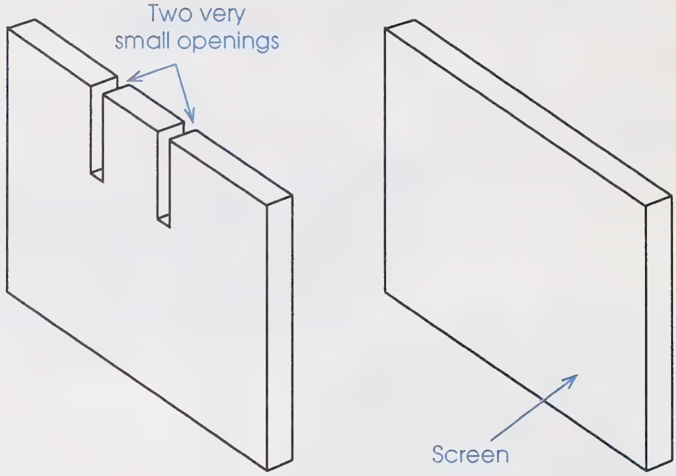
Before you watch the video tape, read through all the questions. As you watch the tape, you may have to periodically stop the program so that you can answer the questions.

1. Why was Newton's particle model given more widespread acceptance than the wave model proposed by Huygens?

2. The diagram that follows shows the setup that Young used to pass light through a very small single opening. Complete the diagram by drawing the pattern that the light would make on the screen.



3. The following diagram shows the setup that Young used to pass light through two very small openings. Complete the diagram by drawing the pattern that the light would make on the screen.

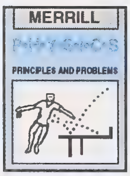


4. At the heart of Young's interpretation of the two-slit interference pattern is his explanation of the bright and dark lines. Use a series of diagrams of crests and troughs to explain the creation of bright and dark lines in this pattern.

Check your answers by turning to the Appendix, Section 3: Activity 1.

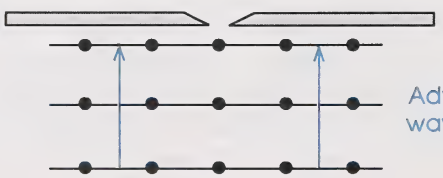
End of Part A

Part B



Carefully read page 392 of your textbook to learn how the terms *diffraction* and *interference* can be applied to light waves.

5. How did Huygens explain the diffraction of waves? Answer by adding labels and a concise explanation to the following diagram.



6. What idea did Young use to explain the bright and dark bands in his two-slit pattern?

Read page 393 of your textbook to discover the detailed explanation for the creation of the bright and dark bands. Be sure to pay especially close attention to Figure 19-2 as you read.

7. What do the semicircles on Figure 19-2 represent?

8. Explain why the solid red lines on Figure 19-2 represent areas of constructive interference.

9. Explain why the dashed red lines on Figure 19-2 represent areas of destructive interference.

Check your answers by turning to the Appendix, Section 3: Activity 1.

End of Part B

An Equation for Two-source Interference

The two circular waves created by diffraction in Young's apparatus were shown to interfere with each other and form nodal and antinodal lines. This pattern is shown on page 393 in Figure 19-2.

Possibly the most remarkable aspect of Young's experiment was the fact that he was able to calculate the wavelength of the light that he used. Go to the textbook now and read page 394 to discover the equation used for this type of calculation. Pay very close attention to the geometric proof for the equation.

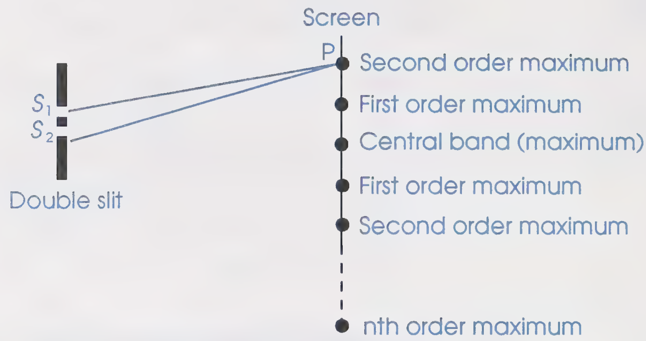
nodal lines – lines of total destructive interference

antinodal lines – lines of constructive interference

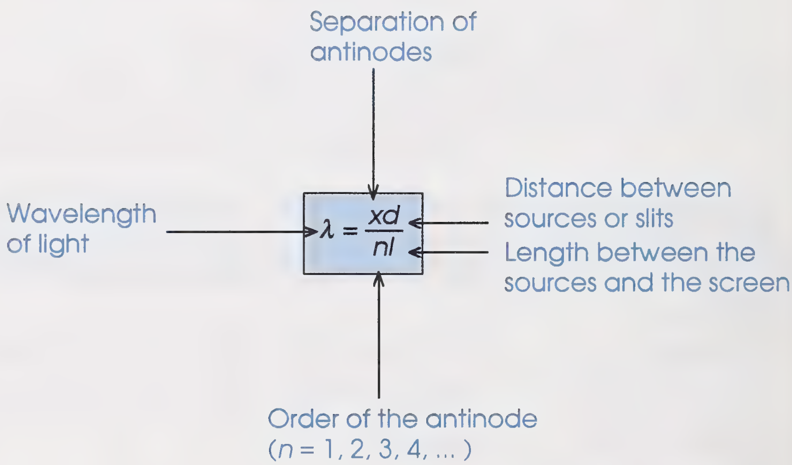
10. The basis for the equation lies in the fact that the two distances, S_1P and S_2P, differ by a particular value. What is that value?

11. Using similar triangles, the book is actually using the relationship $\frac{NS_1}{S_1S_2} = \frac{P_oP}{PO}$ to develop $\frac{\lambda}{d} = \frac{x}{L}$. There are two approximations made to reach this step. List them and state why the equation is still quite accurate.

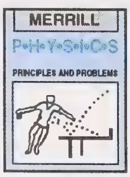
12. Suppose the path difference between S_1P and S_2P had been two wavelengths, forming the second order bright band (i.e. $S_2P - S_1P = 2\lambda$). What would the resulting equation become?



If you consider the answer to the previous question, the general equation would appear as follows:



Note that this equation differs from the one presented in the textbook. The symbol for the distance between the sources and the screen is written as a lower case l and n has been added. The version of the equation shown in the textbook assumes that the first order antinode will always be used, making n equal 1. If n equals 1, it is unnecessary in the equation.



The idea that the value of n becomes 1 when first order lines are used can be seen in the Example Problem on page 395 of your textbook. Study this Example Problem to learn how to match the given data to the variables in the equation.

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

13. Do Practice Problem 1 on page 395 of your textbook.

Check your answers by turning to the Appendix, Section 3: Activity 1.

14. Do Practice Problems 2 to 4 on page 395 of your textbook.

Check your answers by turning to page 679 of your textbook.

Activity 2: Investigating the Interference Equation

One comment that is frequently made by students when they are first working with the two-source interference equation is that it is easy to mix up the variables. The next investigation is designed to help you understand the variables and to prepare you for using these ideas to measure the wavelength of light in Activity 3.

Investigation: Two-source Interference

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [x] E. Synthesizing
- [ ] F. Evaluating

Purpose

In this investigation you will improve your understanding of the two-slit interference equation.

Materials

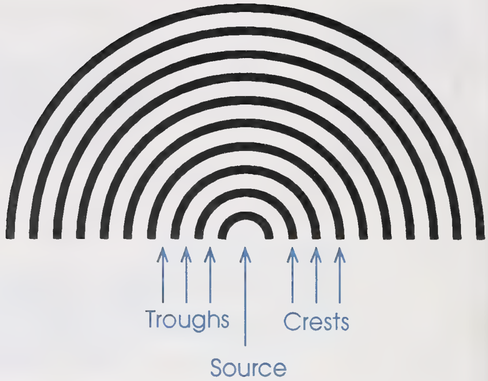
You will need the following materials for this investigation:

- a window with daylight coming through
- masking tape
- a ruler
- the two tear-out pages at the end of the Appendix

Procedure

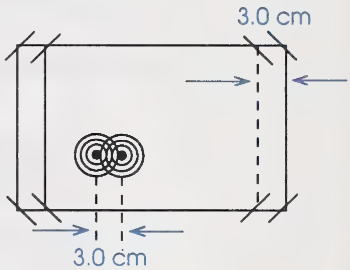
- Tape one of the tear-out pages to the window so that the printed side faces the glass. You should be able to see the pattern of circles through the paper.

- Each black line represents a crest and each white line represents a trough.



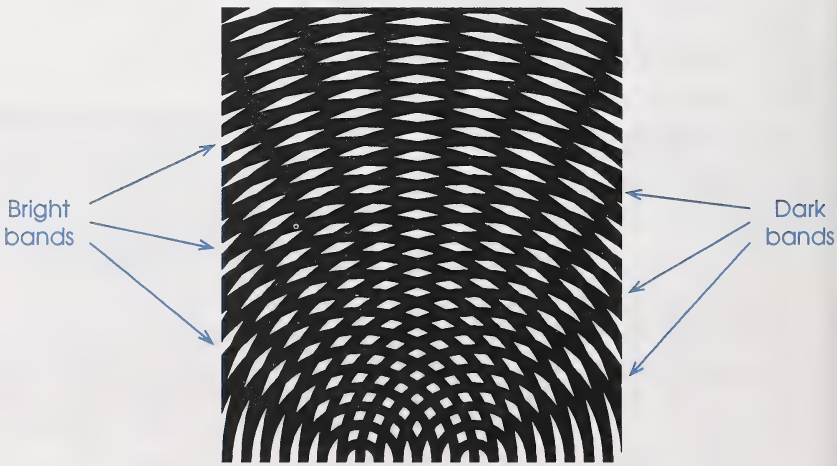
1. Why must the spaces between the black lines represent troughs?

- Tape the other page with the printed side facing the glass on top of the first page so that the sources are exactly 3.0 cm apart. The diagram shows the proper arrangement.



- Note that the top and bottom edges of the patterns are perfectly lined up, while the left and right edges are shifted 3.0 cm.

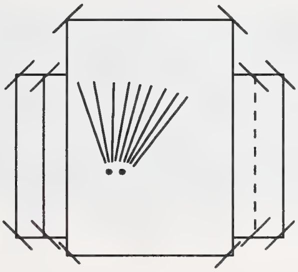
- If light is coming through the window, you should immediately notice a series of bands coming out from between the two sources. The following diagram shows what this will look like.



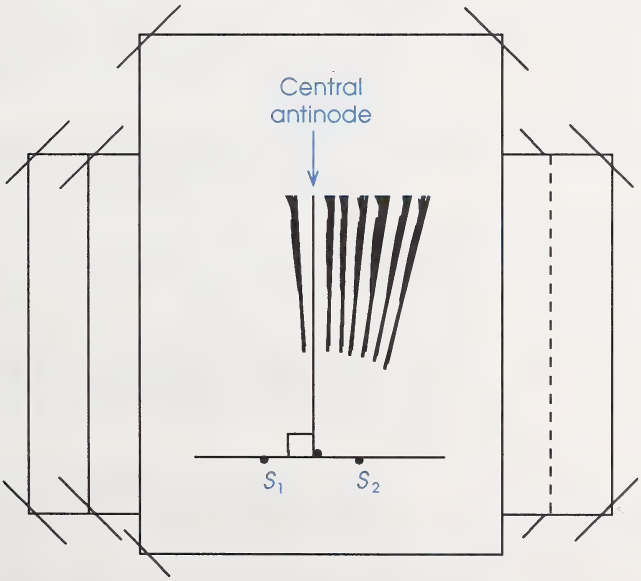
2. Examine the dark bands that come from between the two sources. What do these dark bands represent? Explain your reasoning.

3. What do the bright bands represent? Explain your reasoning.

- Tape a sheet of white paper over the other two sheets that are already on the window. The pattern of the bright and dark bands should still be visible through this third piece of paper. The following diagram shows how to do this.

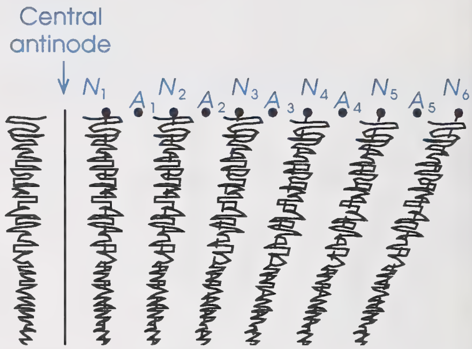


- Draw a horizontal line with a ruler between the sources on the piece of white paper. Also mark the sources, the centre of the sources, and the central antinode. The central antinode can be found by constructing a 90° line with a protractor from the centre of the sources to the top of the pattern. Note that the central antinode is a bright band. The following diagram shows this arrangement.



- Starting at the central antinode and moving to the right along the top of the pattern, mark the centre of each node by making a dot on the piece of white paper. The centre can be accurately located by lining up a clear plastic ruler along the middle of the entire nodal line. The centre of each node will then lie along the edge of the ruler. Identify each node as being the first order node from the centre, the second order node from the centre, and so on, by labelling n_1, n_2, n_3, etc.

- Use a ruler to measure the point midway between each of the nodes. These points are the antinodes. Label the first order antinode A_1, the second order antinode A_2, etc.



- Remove the white piece of paper from the window, but leave the two tear-out pages attached. You will be using the piece of white paper for measurements as you complete this investigation.

4. Measure the distance between the sources (d). Record this value in the data chart.

5. Measure the perpendicular distance (l) between the two sources and the line of points marking the nodes and antinodes. Record this value on the data chart.

6. Measure the distance from the central antinode to each of the other antinodes (x). Record this value on the data chart.

Optional Procedure

Stand back from the window and closely examine the pattern. Can you see how symmetrical it is? If you find this symmetry interesting, you may want to complete this optional procedure. Otherwise, continue with the Analysis section.

- Prepare a data chart that is identical to the one shown on the next page. Label this chart Left Side of Pattern at the top.

- Tape another piece of white paper to the window and locate the sources and the central antinode as you did before.

- Locate the nodes and antinodes to the left of the central antinode.
- Measure d, l, and x and record the values in the chart.
- Compare the data for the left and right sides. Is the pattern truly symmetrical?

Data

Order of the Antinode n	Distance Between Sources d (cm)	Distance Between Sources and Antinodes l (cm)	Distance Between Central Antinode and Each Antinode x (cm)	Wavelength λ (cm)	Percent Error (%)
1					
2					
3					
4					
5					

Analysis

7. Complete the data chart by calculating the value for the wavelength from the data for each antinode.

8. Calculate the actual wavelength by measuring on one of the tear-out sheets with the circles. You can be more accurate if you measure the distance between twenty wavelengths and then divide by 20.

9. Calculate the percent error for each wavelength on the chart by using the actual value from the previous question.

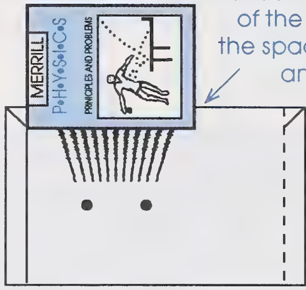
Extending Concepts

An interesting follow-up to this investigation is to explore how the interference pattern is affected if you change one of the variables. You will predict how the pattern will change and then check to see if you are correct.

Changing *l*

10. If the value of l is decreased, predict how the value of x would change if λ and d are kept constant.

- Test your prediction by returning to the window where the tear-out sheets are still taped. Use your textbook and the technique outlined in the diagram to discover how decreasing l influences x.



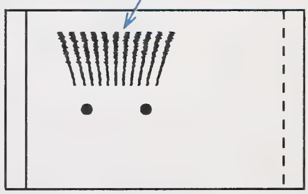
11. Describe how the spacing between antinodes (x) changed as the value of l decreased.

12. Use the interference equation to explain your observations.

Changing *d*

13. If the distance between the sources (d) is decreased, how will the distance between the antinodes (x) change if λ and l are kept constant?

- Test your prediction by returning to the window where the tear-out sheets are still taped. Remove the tape from the tear-out sheet that is in front of the other while holding it in place. Once the tape is removed, slowly move this sheet to close the distance between the sources. The diagram illustrates the technique.



14. Describe how the pattern changes as the distance between the sources decreases.

15. Use the interference equation to explain your observations.

- Remove the tear-out sheets from the window. Save all three sheets of paper for use in future investigations.

Conclusions

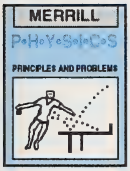
16. Have you been able to confirm that the equation is valid? Do the variables influence each other in a way that is consistent with the equation?

Check your answers by turning to the Appendix, Section 3: Activity 2.

Activity 3: A Wavelength for Light

In this activity you will apply all your knowledge of the interference of light to obtain values for the wavelengths of different colours. Although the basic physics will be the same, you will modify the technique developed by Young by using a **diffraction grating**.

diffraction grating – a piece of glass or plastic etched with thousands of parallel lines that help to produce an interference pattern



To learn what a diffraction grating is and how it works, read page 400 in your textbook.

1. What is the typical spacing between the lines etched on a diffraction grating?

2. Suppose that you have a grating with 360 lines per millimetre. What is the distance between any two consecutive lines? Use your answer to develop an equation for finding the distance between consecutive lines on a diffraction grating.

3. A diffraction grating has 530 lines per millimetre. Use the answer to the previous question to calculate the distance between two consecutive lines.

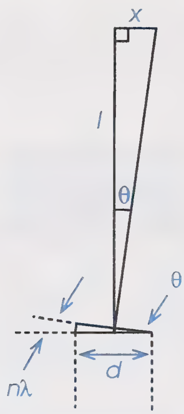
4. What is the advantage of using a diffraction grating when doing an investigation to measure the wavelength of light?

You will be using a more accurate equation to calculate wavelength in this investigation. You may recall from the textbook explanation of the equation $\lambda = \dfrac{xd}{nl}$ that the equation is based on approximations valid only for the case that the angle θ is small. For example, if the angle is less than 6°, the equation can give wavelength values with three significant digits of precision. However, if the angle is between 6° and 12°, the value for wavelength will only be precise to two significant digits. Clearly this equation is an approximation that depends on the size of the angle. Another approach is to calculate angle θ and use this value to determine the wavelength.

From the small triangle:

$$\sin\theta = \frac{n\lambda}{d}$$

$$\boxed{\lambda = \frac{d\sin\theta}{n}}$$



From the large triangle:

$$\tan\theta = \frac{x}{l}$$

$$\boxed{\theta = \tan^{-1}\left(\frac{x}{l}\right)}$$

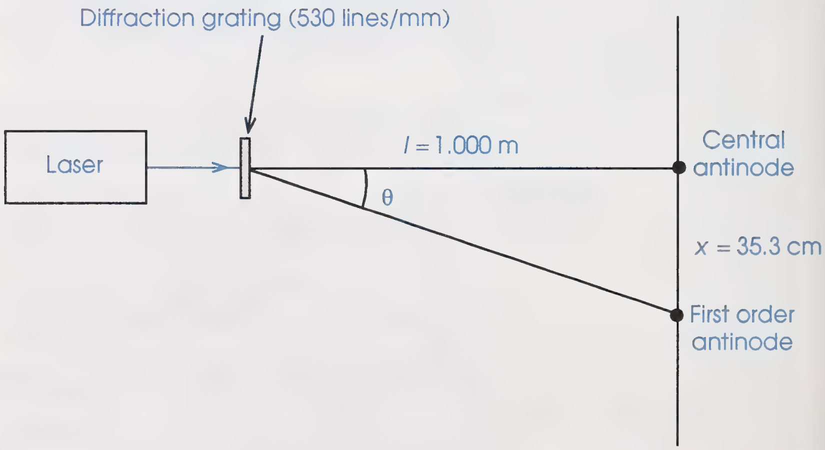
Substitute the value of θ calculated from the large triangle into the equation from the small triangle.

$$\boxed{\lambda = \frac{d\sin\theta}{n}}$$

The following example illustrates the use of this approach.

Example

Use the data to find the wavelength of the laser light.



Step 1: Find d.

$$d = \frac{1\text{ mm}}{530\text{ lines}}$$
$$= \frac{1 \times 10^{-3}\text{ m}}{530\text{ lines}}$$
$$= 1.887 \times 10^{-6}\text{ m}$$

Step 2: Calculate θ.

$$\tan\theta = \frac{x}{l}$$
$$\theta = \tan^{-1}\left(\frac{x}{l}\right)$$
$$= \tan^{-1}\left(\frac{0.353\text{ m}}{1.000\text{ m}}\right)$$
$$= 19.44°$$

Step 3: Calculate λ.

$$\lambda = d\sin\theta$$
$$= \left(1.887 \times 10^{-6}\text{ m}\right)\left(\sin 19.44°\right)$$
$$= 6.28 \times 10^{-7}\text{ m}$$

5. Use the data provided in the previous example to calculate the wavelength using the equation $\lambda = \dfrac{xd}{nl}$.

6. If the wavelength of light produced by a laser is 6.328×10^{-7} m, calculate the percent error for the wavelength resulting from each method.

7. Use Figure 19-4 on page 394 of the textbook to explain why the method using $\lambda = d\sin\theta$ is more accurate.

8. Do Problem 11 on page 404 of your textbook using the equations $\theta = \tan^{-1}\left(\frac{x}{l}\right)$ and $\lambda = d\sin\theta$.

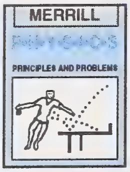
Check your answers by turning to the Appendix, Section 3: Activity 3.

Investigation: Determining the Wavelength of Light

Purpose

In this investigation you will measure the wavelengths of four colours of light.

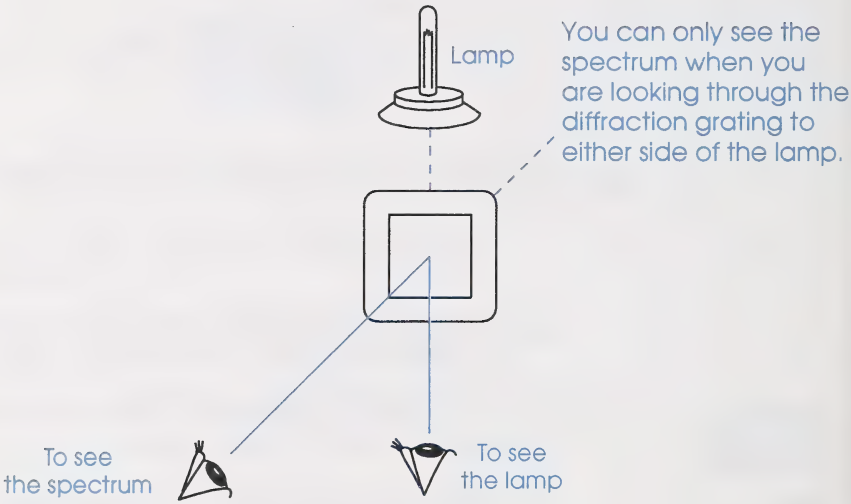
Materials



The materials for this investigation are listed on page 399 of your textbook. You may need to use the play dough that you made earlier if you don't have clay.

Procedure

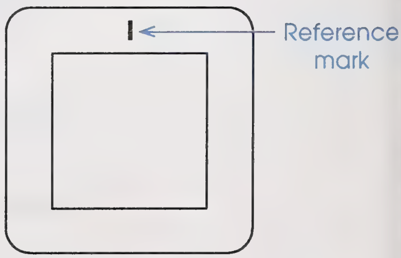
- Plug in the lamp and look through the diffraction grating at the source. When you look off to the side of the light, you should see a continuous spectrum. If you do not, rotate the grating through 90° and try again. Make sure that you see the spectrum at the side before you proceed. Unplug the lamp.

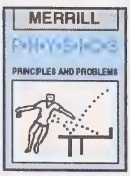


- When you have the diffraction grating oriented in the proper direction, mount it in some play dough exactly 1.000 m from the lamp. Elevate the grating about 3 or 4 cm by placing it on a book so that it is easier to look through.

- Make a vertical pencil mark on the top edge of the grating. You will use this mark to line up the colours of the spectrum.

- Complete the rest of the procedure as outlined on page 399 of your textbook.





9. Record your data on the following data chart.

Data

Colour	Distance from Central Antinode (The Lamp) to First Order Antinode x (m)	Distance Between Source (Grating) and Lamp l (m)	Diffraction Angle θ (°)	Distance Between Lines on Grating d (m)	Wavelength λ (m)
Orange					
Yellow					
Green					
Blue					

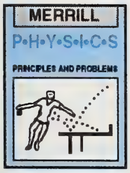
Analysis

10. Use the data printed on the grating to calculate the distance between lines on the grating. Record this value on the data chart.

Conclusions

11. Calculate the wavelength of each colour using the equations $\theta = \tan^{-1}\left(\frac{x}{l}\right)$ and $\lambda = \frac{d\sin\theta}{n}$. Record the values on the data chart.

12. Compare your values for wavelengths with the range presented in Figure 16-1 on page 330 of your textbook. Are your values within this range?



Applications

13. Do Problems 8 and 14 on pages 404 and 405 of your textbook. Be sure to use the equations $\theta = \tan^{-1}\left(\frac{x}{l}\right)$ and $\lambda = d\sin\theta$ in your answers.

Now that you've nearly come to the end of this module, it would be a good idea to quickly skim through your module booklet and identify the new equations.

14. Identify all the new equations that were introduced in this module. Record these equations under appropriate headings on the sheet containing the main equations from the other modules.

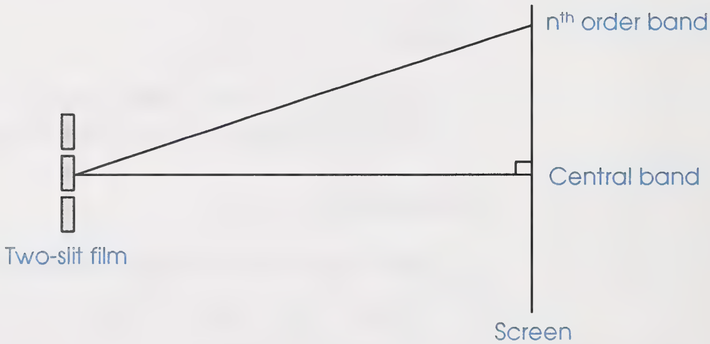
Check your answers by turning to the Appendix, Section 3: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. a. Using the sketch below, locate and label the values x, d, l, and θ.



b. What do the variables n and λ represent in the formulas $\lambda = \frac{xd}{nl}$ and $\lambda = \frac{d \sin \theta}{n}$?

2. Orange light falls on two slits separated by 2.85×10^{-3} cm. The second order bright line is found 52.5 mm from the central bright line when the screen is placed 1.250 m from the slits.

a. What is the wavelength of this light? Use the equation $\lambda = \frac{xd}{nl}$ and express your answer in nanometres.

b. Repeat the calculations using the equations $\theta = \tan^{-1}\left(\frac{x}{l}\right)$ and

$$\lambda = \frac{d \sin \theta}{n}.$$

c. Why do both methods give very nearly the same answer for parts a and b?

3. Make a sketch of what you saw when you looked through the diffraction grating in Activity 3. Be specific with colours, lines, etc.

Check your answers by turning to the Appendix, Section 3: Extra Help.

Enrichment

Do **one** of the following activities.

1. Speed of Light in Water

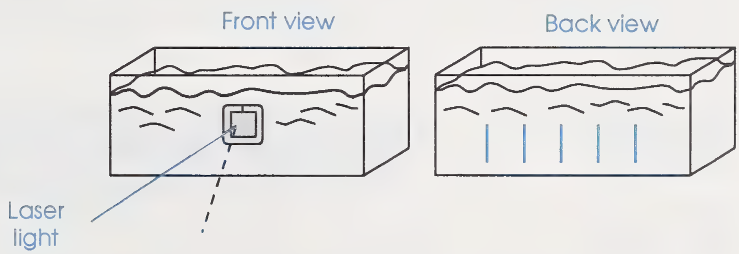
Caution

If you have access to a laser, perform the following experiment to determine the speed of light in water. If you do not have access to a laser, carefully read through the procedure and then do question 1. d. where the data is supplied.

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

- Set up your equipment as shown in the following diagrams. Make sure that the grating is taped to the **inside** of the aquarium.

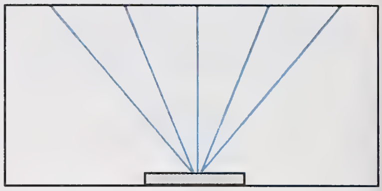


a. Calculate d from the data printed on the diffraction grating.

b. Use a ruler to measure values for x and l.

Be careful that you are observing light coming directly from the grating and not a reflection coming from another side of the aquarium.

- Adding one or two drops of milk to the water allows you to see the beam as it travels through the water.



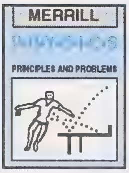
c. After all of the measurements have been made, use these values to calculate the wavelength of the light in water. Then, using the known wavelength of your laser and Snell's law (from Module 6), calculate the speed of light in water. Compare this value to the known value of $v_{water} = 2.26 \times 10^8$ m/s.

d. Use the following sample data to calculate the speed of light in water. The diffraction grating has 5300 lines/cm.

$$x = 8.0 \text{ cm}$$
$$l = 31.2 \text{ cm}$$
$$\lambda_{air} = 632.8 \text{ nm}$$

2. Applications of the Diffraction of Light

spectrometer – a device used to measure angles of deflection of light after diffracting or refracting in order to calculate wavelengths



a. Do Critical Thinking question 2.4 on page 402 of the textbook. This question introduces the term spectrometer.

b. Read the section in the text titled Resolving Power of Lenses on pages 401 and 402 of your textbook. Then answer Concept Review question 2.3 on page 402.

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

This section has provided an opportunity to see how the physics of two-source interference patterns can be applied to light. You have seen how the pattern can be analysed to produce an equation that allows you to calculate the wavelength of light. The applications of these concepts are numerous.

In the introduction to this section you were introduced to the idea that compact disc players often employ a three-beam laser. You should now be able to understand that the single laser beam is split by a diffraction grating to form the central antinode and the first-order antinodes on each side. The next time you see someone listening to a CD player, think back to the patterns of nodal and antinodal lines that help make this technology possible.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 3.

MODULE SUMMARY

This module has allowed you to apply most of the main ideas from the two previous modules to some very useful technologies. You've seen how the reflection, refraction, diffraction, and interference of light play a key role in your life. The very fact that you are reading this page means that light is reflecting from the paper and is then being focused by the lens system of your eyes. Hopefully this module has given you new insights into the significance of light in the world around you.

Appendix

Glossary

Activities

Extra Help

Enrichment

Glossary

accommodation – the ability of the lens in the eye to adjust its focal length through the action of the ciliary muscles

antinodal lines – lines of constructive interference

astigmatism – a defect present in an eye that will not focus sharply in all planes

centre of curvature – the centre of the spherical surface that makes a curved mirror or lens

chromatic aberration – the effect of colours refracting at different angles and having different focal points

coherent light – light waves that are all in phase

compound lens system – uses more than one lens

concave lens – a lens which is thicker at the edges than in the middle and which causes light rays to diverge

concave mirror – reflects light from its inner surface which curves away from the viewer

convex lens – a lens which is thicker in the middle than at the edges and which causes light rays to converge

convex mirror – reflects light from its outer surface which curves out towards the viewer

diffraction – the spreading of waves as they pass a barrier

diffraction grating – a piece of glass or plastic etched with thousands of parallel lines that help to produce an interference pattern

focal point – the point on the principal axis to which parallel incident rays will converge

hyperopia – farsightedness; the focal length of the eye is too long causing nearby objects to be blurred

interference – two waves interact and combine to form a single wave

lens aberrations – deviations in the behavior of light passing through an actual lens. The behavior of light that is predicted by ray diagrams occurs only in ideal, thin lenses.

monochromatic light – light of one colour (or wavelength)

myopia – nearsightedness; the focal length of the eye is too short, causing objects at a distance to be blurred

near point – the closest distance for which the lens of the eye can create a sharp image on the retina

nodal lines – lines of total destructive interference

principal axis – a line perpendicular to the centre of a mirror or lens

real image – an image formed by the convergence of actual light rays. A real image can be formed on a screen

spectrometer – a device used to measure angles of deflection of light after diffracting or refracting in order to calculate wavelengths

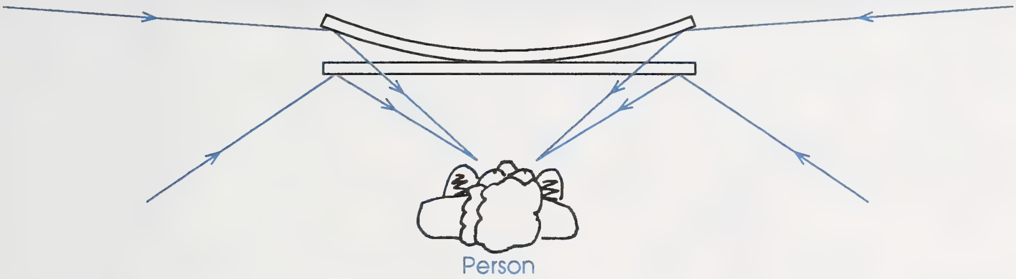
spherical aberration – the effect of parallel light rays at the edges of a curved mirror or lens reflecting or refracting to different focal points

virtual image – an image from which light rays appear to originate. A virtual image cannot be formed on a screen.

Suggested Answers

Section 1: Activity 1

1. A curved mirror allows objects that would ordinarily be outside the field of view of a plane mirror to be seen.

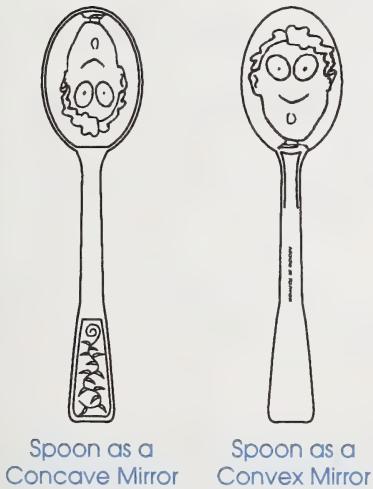


2. This effect is also noticeable on the sideview mirrors of cars, the back of a spoon, shiny metal containers, etc. Any smooth surface that reflects light and has its centre curved towards you will produce such an image.

3. A flashlight or headlight uses a concave reflector to send light rays **outwards** in a relatively parallel beam. A satellite dish **gathers** parallel microwave rays into a focal point.

4. The side of the spoon that holds the soup is concave. The bottom side of the spoon is convex.

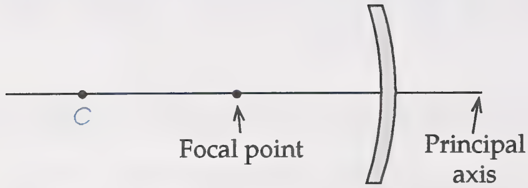
5.



6. All concave mirrors will have the effect of inverting the image at long distances and then presenting an upright (or erect) image at closer distances. The point at which the transition occurs will be different for each type of concave mirror.

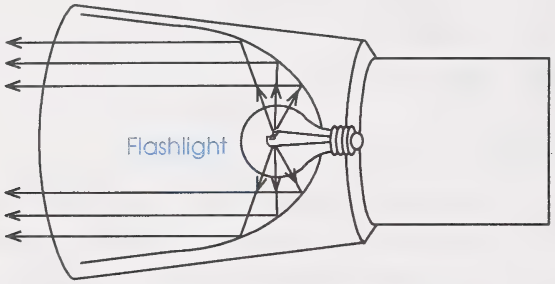
Section 1: Activity 2

1.



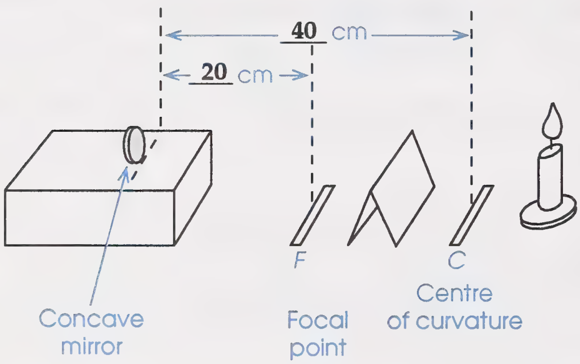
2. The reflected ray will pass through or near the focal point.

3.



4. A real image can be formed on a screen. A virtual image cannot be formed on a screen.

5.



6. This question is answered on the previous diagram.

7. A convex mirror only produces a virtual image.

8. The image created by a convex mirror could be seen by looking into the mirror. The image would appear to be behind the mirror, but no light rays actually come from its apparent position behind the mirror. This is why this image could not be formed on a screen.

9. The image of the distant object is upright, smaller, and appears to be much further away than the object itself.

10.

Images Formed by a Concave Mirror				
Location of Candle	**Distance Between Mirror and Candle (cm)**	**Distance Between Mirror and Image (cm)**	**Size of Image Compared to Candle**	**Orientation of Image**
Beyond *C*	50	33	smaller	inverted
At *C*	40	40	same size	inverted
Between *C* and *F*	30	60	larger	inverted
At *F*	20	no image	no image	no image
Between *F* and Mirror	10	virtual image	larger	upright

11. This question is answered on the previous chart.

12. A real image is created by the concave mirror when the candle is placed beyond the focal point.

13. A virtual image is created by the concave mirror when the candle is placed between the focal point and the mirror.

14. When the candle is placed at the focal point, no image is created.

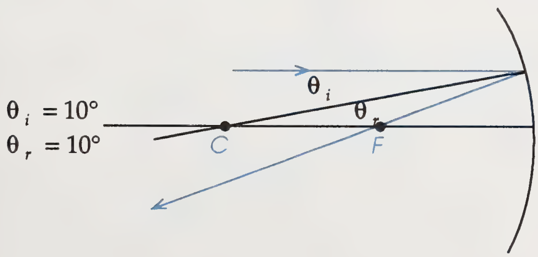
15. A convex mirror produces a virtual image that is smaller than the object. A concave mirror produces a virtual image that is larger than the object.

16. The concave mirror would not give you the significant view of the entire store that the convex mirror provides.

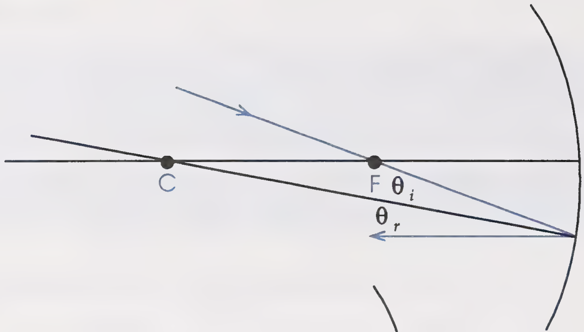
Section 1: Activity 3

1. The radius of a sphere is perpendicular to the surface of the sphere at the point of intersection.

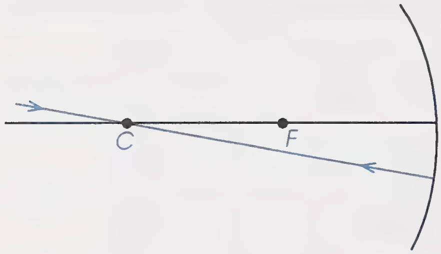
2.



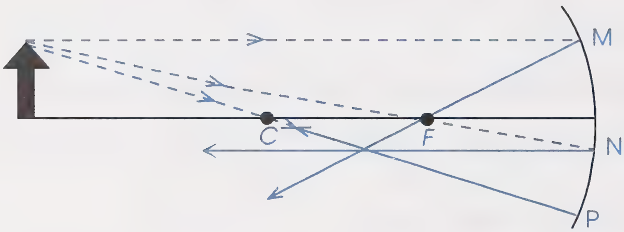
$\theta_i = 7°$
$\theta_r = 7.5°$



$\theta_i = 0°$
$\theta_r = 0°$



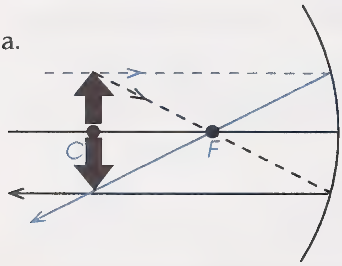
3. a.



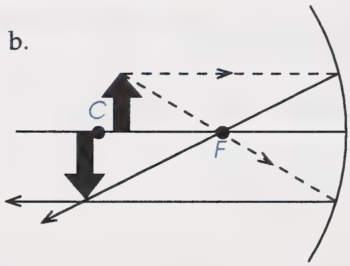
b. The three reflected rays intersect at the same location.

c. The tip of the image should be located at this intersection.

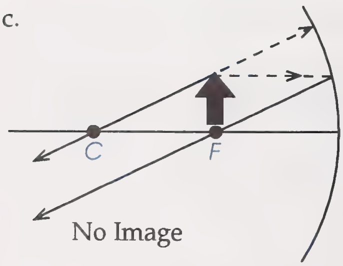
4. a.



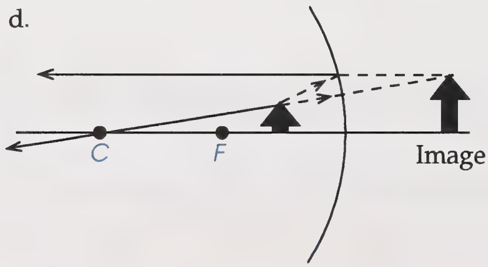
b.



c.



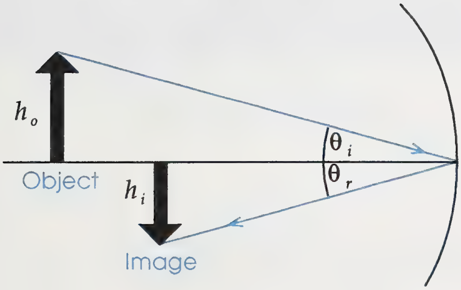
d.



5. An approximate answer can be obtained by noting that since the image is about twice as large as the object, the magnification factor is 2. An exact answer can be found by using the equation.

$$\begin{aligned} m &= \frac{h_i}{h_o} \\ &= \frac{21.5\ \text{mm}}{11\ \text{mm}} \\ &= 1.95 \\ &= 2.0 \end{aligned}$$

6.



$$\boxed{\theta_i = \theta_r}$$

By the law of reflection

$$\boxed{\tan\theta_i = \tan\theta_r}$$

If the angles are equal, the tangents of the angles are equal.

Substitute the opposite and adjacent sides of both triangles.

$$\boxed{\frac{h_o}{d_o} = \frac{h_i}{d_i}}$$

Rearrange the equation.

$$\boxed{\frac{h_i}{h_o} = \frac{d_i}{d_o}}$$

7.

Sign Conventions for Mirror and Magnification Equations					
	m	h_i	d_o	d_i	f
Positive Value	upright image	upright image	a real object location	location of a real image	focal length of a concave mirror
Negative Value	inverted image	inverted image	location of a virtual object	virtual image location	focal length of a convex mirror

8. If h_i or m is negative, the image has been inverted from the original position of the object.

9.

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

Manipulate the right side of the equation so that both terms have a common denominator. Note that this is equivalent to multiplying each term by 1.

$$\frac{1}{d_i} = \frac{1}{f}\left(\frac{d_o}{d_o}\right) - \frac{1}{d_o}\left(\frac{f}{f}\right)$$

$$\frac{1}{d_i} = \frac{d_o}{f d_o} - \frac{f}{f d_o}$$

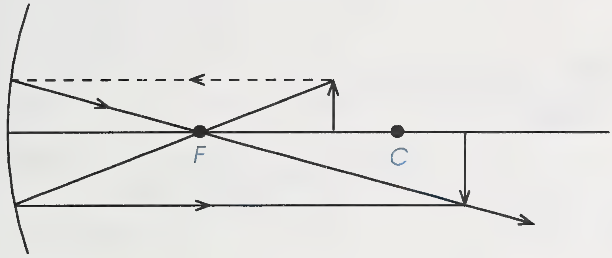
Now that the terms have a common denominator, they can be combined.

$$\frac{1}{d_i} = \frac{d_o - f}{f d_o}$$

Take the reciprocal of both sides to solve for d_i.

$$d_i = \frac{f d_o}{d_o - f}$$

10. a. Find the image by means of a ray diagram. Use the diagram supplied below.



b. $\frac{1}{f}=\frac{1}{d_i}+\frac{1}{d_o}$

$d_i=\frac{fd_o}{d_o-f}$

$d_i=\frac{(3.0\text{ cm})(5.0\text{ cm})}{5.0\text{ cm}-3.0\text{ cm}}$

$d_i=7.5\text{ cm}$

A real image 7.5 cm in front of the mirror.

c. $\frac{h_i}{h_o}=\frac{-d_i}{d_o}$

$h_i=\frac{-d_ih_o}{d_o}$

$h_i=\frac{-(7.5\text{ cm})(8.0\text{ mm})}{5.0\text{ cm}}$

$h_i=-12\text{ mm}$

The inverted image is 12 mm tall.

11. Textbook question 7.a.:

$h_o=4.0\text{ cm}$
$d_o=10.0\text{ cm}$
$f=16.0\text{ cm}$
$d_i=?$

$\frac{1}{f}=\frac{1}{d_i}+\frac{1}{d_o}$

$d_i=\frac{fd_o}{d_o-f}$

$d_i=\frac{(16.0\text{ cm})(10.0\text{ cm})}{(10.0-16.0)\text{ cm}}$

$d_i=-26.\overline{6}\text{ cm}$

$=-27\text{ cm}$

The image is 27 cm behind the mirror (virtual).

Textbook question 7.b.:

$h_o=4.0\text{ cm}$
$d_o=10.0\text{ cm}$
$d_i=-26.\overline{6}\text{ cm}$
$h_i=?$

$\frac{h_i}{h_o}=\frac{-d_i}{d_o}$

$h_i=\frac{-d_ih_o}{d_o}$

$h_i=\frac{-(-26.\overline{6}\text{ cm})(4.0\text{ cm})}{10.0\text{ cm}}$

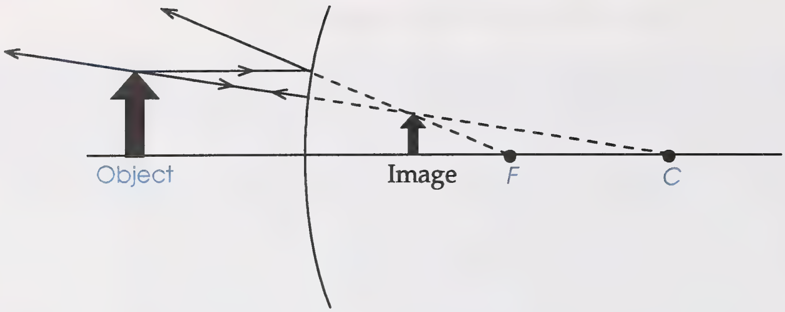
$h_i=11\text{ cm}$

The upright image is 11 cm tall.

12. The answers to these problems are found on page 678 of your textbook.

13. The image created by a convex mirror is always smaller than the object. The image is always a virtual image because it appears to be located behind the mirror.

14.



15. $d_o = 15.0\text{ cm}$
$d_i = -6.0\text{ cm}$

$$m = \frac{-d_i}{d_o}$$

$$m = \frac{-(-6.0\text{ cm})}{15\text{ cm}}$$

$$m = \frac{2}{5} = 0.40$$

The positive value for magnification indicates an upright image. This will always be the case for convex mirrors.

16. Textbook question 10.a.:

$f = -12\text{ cm}$
$h_o = 6.0\text{ cm}$
$d_o = 60.0\text{ cm}$
$d_i = ?$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{f\,d_o}{d_o - f}$$

$$d_i = \frac{(-12\text{ cm})(60.0\text{ cm})}{(60.0\text{ cm}) - (-12\text{ cm})}$$

$$d_i = -10\text{ cm}$$

The image is virtual and 10 cm behind the mirror.

Textbook question 10.b.:

$h_o = 6.0\text{ cm}$
$d_o = 60.0\text{ cm}$
$d_i = -10\text{ cm}$
$h_i = ?$

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$h_i = \frac{(-10\text{ cm})(6.0\text{ cm})}{(60.0\text{ cm})}$$

$$h_i = 1.0\text{ cm}$$

The diameter appears to be 1.0 cm.

17. The answers to these problems can be found on pages 678 and 679 of your textbook.

18. a. Yes, it does. The radius of curvature is twice the focal length and is within the range at $r = 156 \text{ cm} = 1560 \text{ mm}$.

b. $f = -0.780 \text{ m}$
$d_o = 60 \text{ m}$
$d_i = ?$
$m = ?$

Step 1: Find d_i.

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$
$$\frac{1}{d_i} = \frac{d_o - f}{f d_o}$$
$$d_i = \frac{f d_o}{d_o - f}$$
$$= \frac{(-0.780 \text{ m})(60 \text{ m})}{(60 \text{ m}) - (-0.780 \text{ m})}$$
$$= -0.790$$

Step 2: Calculate m.

$$m = \frac{-d_i}{d_o}$$
$$m = \frac{-(-0.770 \text{ m})}{60 \text{ m}}$$
$$m = 0.013$$

Section 1: Follow-up Activities

Extra Help

1.

	Location of Object	Location of Image	Type of Image (Virtual/Real)	Size of Image (Smaller, Bigger, Same)
Concave	beyond C	between C and F	real	smaller
	at C	at C	real	same
	between C and F	beyond C	real	bigger
	at F	none	none	—
	between F and A	behind mirror	virtual	bigger
Convex	anywhere	behind mirror	virtual	smaller

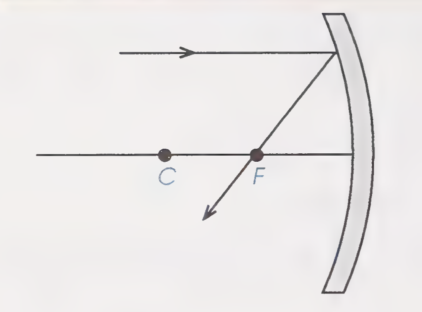
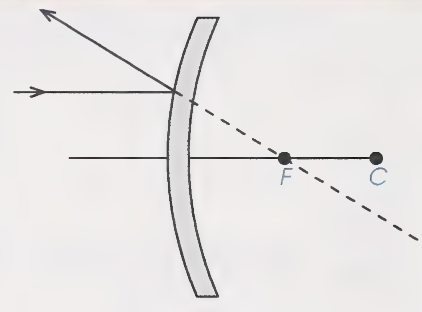
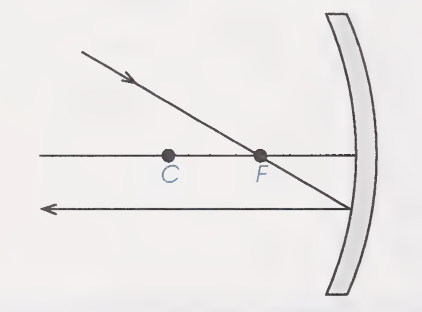
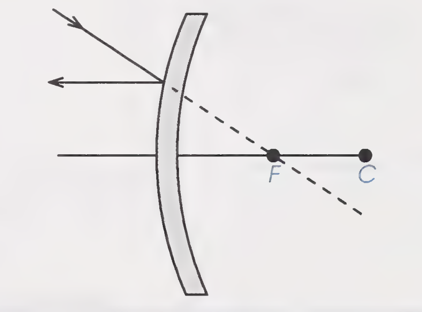
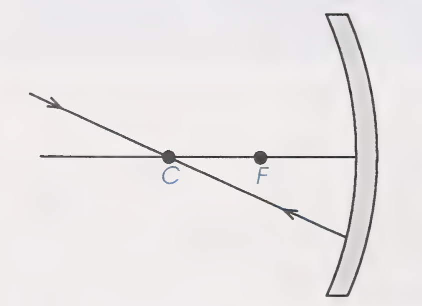
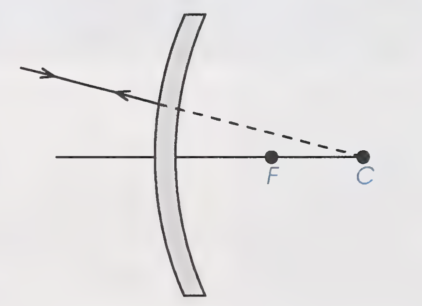
2. a. The image is virtual.

   b. The image is inverted.

   c. The mirror is convex.

   d. The image is inverted.

3.

Concave Mirror	Convex Mirror
	
	
	

4. $d_i = 30$ cm
$f = 10$ cm (half the distance to C)
$d_o = ?$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$d_o = \frac{f\,d_i}{d_i - f}$$
$$d_o = \frac{(10.0\text{ cm})(30.0\text{ cm})}{(30.0 - 10.0)\text{ cm}}$$
$$d_o = 15.0\text{ cm}$$

5. $f = -40.0$ cm
$= -0.400$ m
$d_o = 6.0$ m
$d_i = ?$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$
$$d_i = \frac{f\,d_o}{d_o - f}$$
$$d_i = \frac{(-0.400\text{ m})(6.0\text{ m})}{(6.0 + 0.400)\text{ m}}$$
$$d_i = -0.38\text{ m}$$

The image is virtual and located 38 cm behind the mirror. The image will be erect and smaller than the object since a convex mirror is being used.

Enrichment

1. Focal lengths will vary. The lamp is located at the focal point so that the light rays reflected from the silvered surface will leave the headlight relatively parallel to each other.

2. a. **Step 4: Combine Equations to eliminate $\frac{h_i}{h_o}$.**

Since $\frac{h_i}{h_o} = \frac{h_i}{h_o}$, $\frac{f}{d_o - f} = \frac{d_i - f}{f}$.

b. **Step 5: Rearrange Using Algebra to Obtain the Mirror equation**

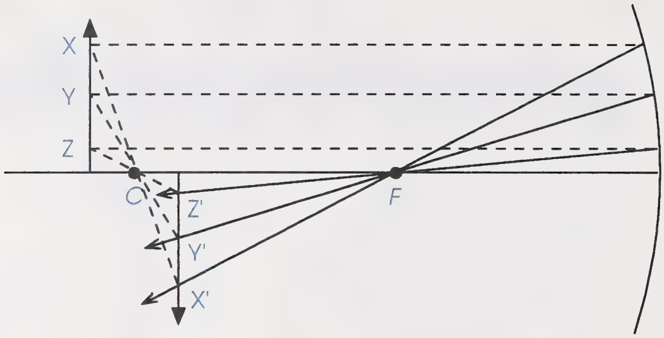
$$f^2 = (d_o - f)(d_i - f)$$
$$f^2 = d_o d_i - f d_i - f d_o + f^2$$
$$0 = d_o d_i - f d_i - f d_o$$

$$f d_i + f d_o = d_o d_i$$
$$d_i + d_o = \frac{d_o d_i}{f}$$
$$\frac{d_i + d_o}{d_o d_i} = \frac{1}{f}$$
$$\frac{d_i + d_o}{d_o d_i} = \frac{1}{f}$$
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

c. The two triangles closest to the mirror contain approximations for the measurement of focal length as the base of their triangles.

d. The approximations will approach the actual focal length when the object is small (h_o is small) or the radius of curvature is large (f is large).

3.



Section 2: Activity 1

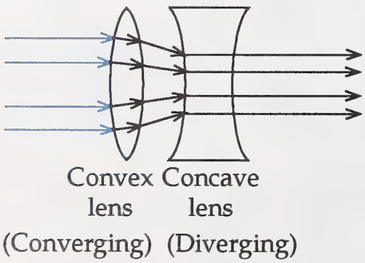
1. A lens is a block of transparent material with an index of refraction different from that of air. Usually at least one of its faces is spherical.

2. A convex lens is thicker in the middle than at the edges. A concave lens is thicker at the edges than in the middle.

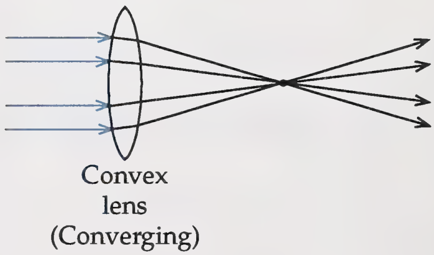
3. A concave lens is also called a divergent lens because it diverges (spreads out) the light rays. A convex lens causes light to converge (come together).

4. Refraction allows a lens to change the direction of light rays.

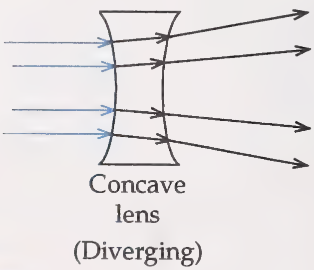
5. a.



b.



c.

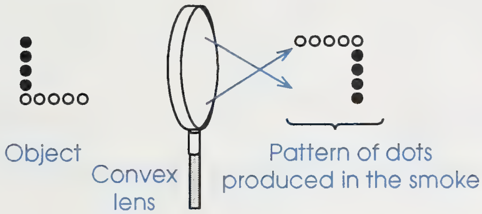


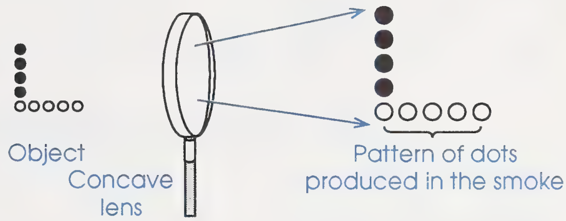
6. This question is answered on the previous diagrams.

7. This question is answered on the previous diagrams.

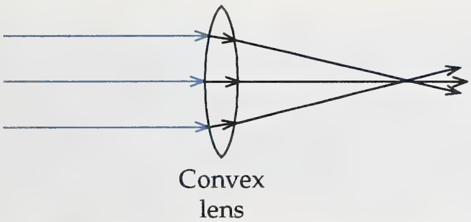
8. No, the light rays do not travel at the same speed through the lens as they do through the air. The lens shown in the video is filled with coloured water, which is a slower medium for light rays. This means that the light rays decrease in speed as they enter the lens and increase as they leave the lens. It is the change in speed that causes the bending of the light rays at each face of the lens.

9.

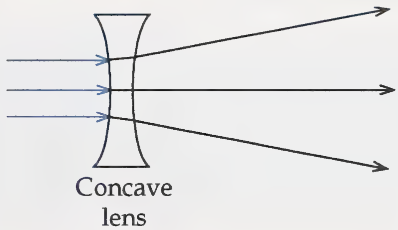




10. a.

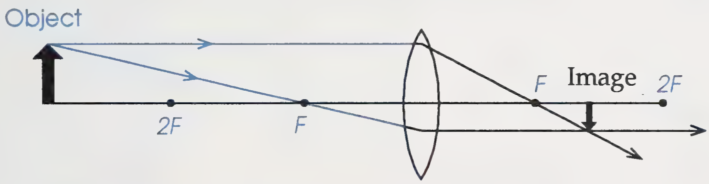


b.



11. This question is answered on the previous diagrams.

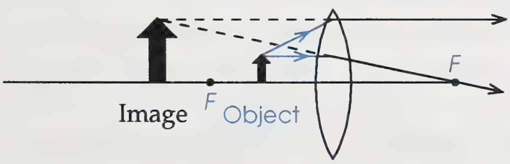
12. a.



b. This question is answered on the previous diagram.

c. The image is real because light rays actually come from that point. If a screen was placed there, the image would form on the screen.

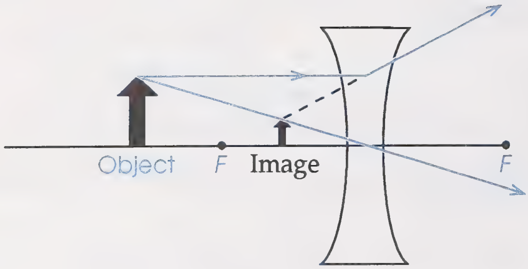
13.



14. a. This question is answered on the previous diagram.

b. The image is virtual because light rays only **appear** to come from the image. If a screen was placed at the location of the image, no light would strike the screen.

15.



16. a. This question is answered on the previous diagram.

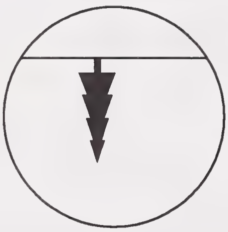
    b. The image is a virtual image because light only appears to come from the image. If a screen was placed at the position of the image, no light would strike the screen.

Section 2: Activity 2

1. Image of a distant object through a concave lens

2. As the concave lens moved closer to your eyes, you should have seen the upright image of the object become larger.

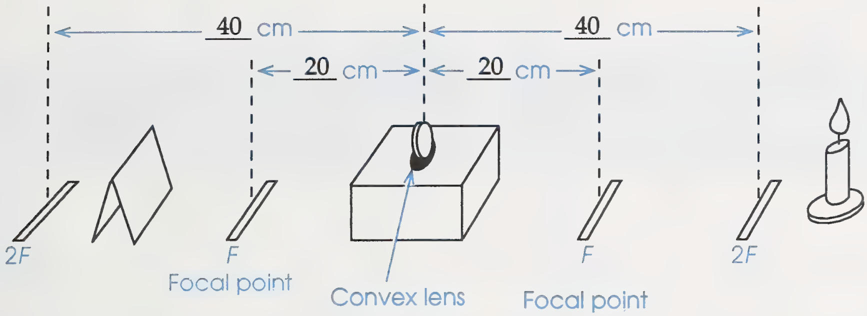
3. Image of a distant object through a convex lens



4. As the convex lens was brought closer, the image of the tree got larger and then it seemed to disappear in a blur. As the lens moved in closer, the image reappeared right side up. As the lens moved very close to the eye, the image remained right side up, but got smaller.

5. Your values may differ from those presented here, depending on the characteristics of the lens that you use.

Setup of the Apparatus for finding Images in a Convex Lens



6. This question is answered on the previous diagram.

7.

Images Formed by a Convex Lens				
Location of Candle	**Distance Between Lens and Candle (cm)**	**Distance Between Lens and Screen (cm)**	**Size of Image Compared to Candle**	**Orientation of Image**
Beyond 2*F*	50	33	smaller	inverted
At 2*F*	40	40	same size	inverted
Between *F* and 2*F*	30	60	larger	inverted
At *F*	20	no image	no image	no image
Between *F* and Mirror	10	virtual image – not on screen	larger	right side up

8. This question is answered on the previous data chart.

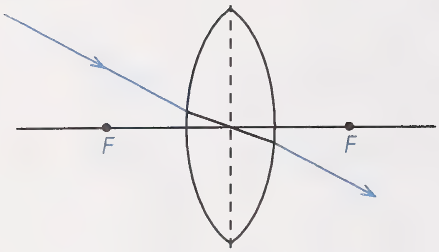
9. The candle must be located beyond *F*.

10. The candle must be located between *F* and the convex lens to create a virtual image.

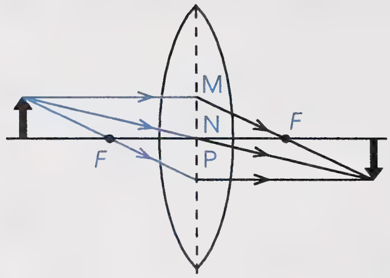
11. When the candle is located at *F*, no image is formed.

12. Although both images are upright, the image produced by a concave lens is always reduced in size.

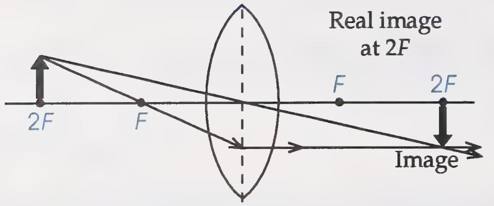
13.



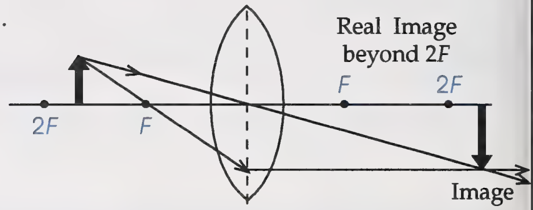
14.



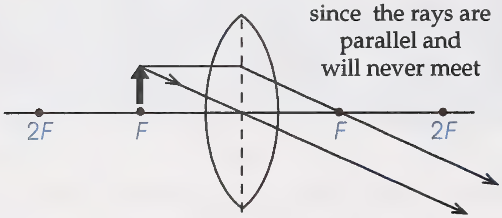
15. a.



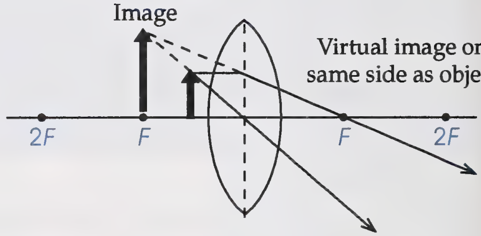
b.



c.

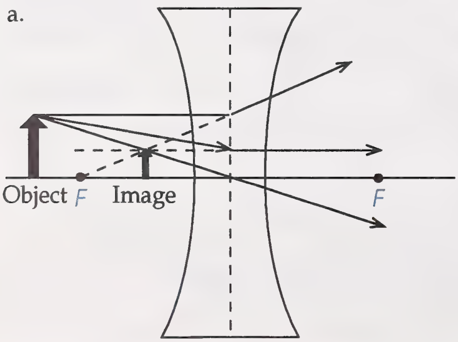


d.

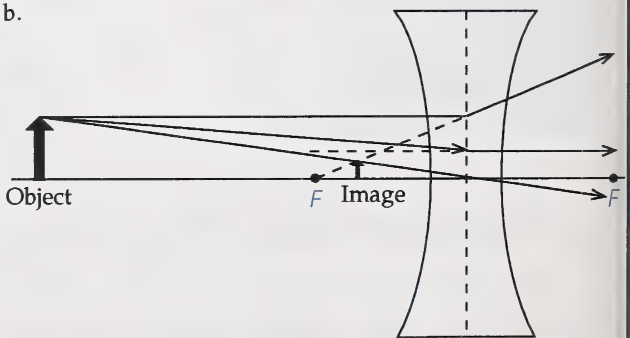


16. These results should be consistent with the results from the investigation.

17. a.



b.



Section 2: Activity 3

1.

Sign Convention for Equations Applied to Lenses					
	m	h_i	d_o	d_i	f
Positive Value	upright image	upright image	real object	real image	The lens is convex.
Negative Value	inverted image	inverted image	virtual object	virtual image	The lens is concave.

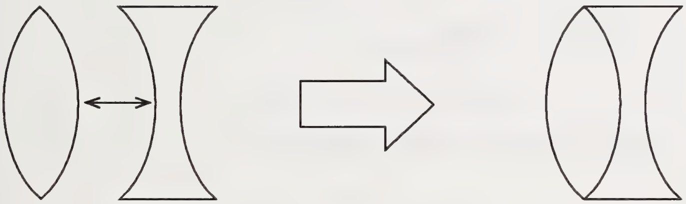
2. The only column that is different is the last one for focal length. If the focal length is positive, the mirror is concave but the lens is convex. This should not be interpreted as a contradiction because both devices converge light rays. The devices which diverge light rays, the convex mirror and the concave lens, both have a negative focal length.

3. Yes, the sign conventions apply in a consistent way to these two Example Problems.

4. The answers to these problems are found on page 679 of your textbook.

5. Spherical aberration can be eliminated by not passing light rays through the edge of the lens and by designing the lens to be as close as possible to the ideal thin shape.

6. A two-lens system is used. Most often, one convex lens and one concave lens will be put together to eliminate the effects of chromatic aberration.

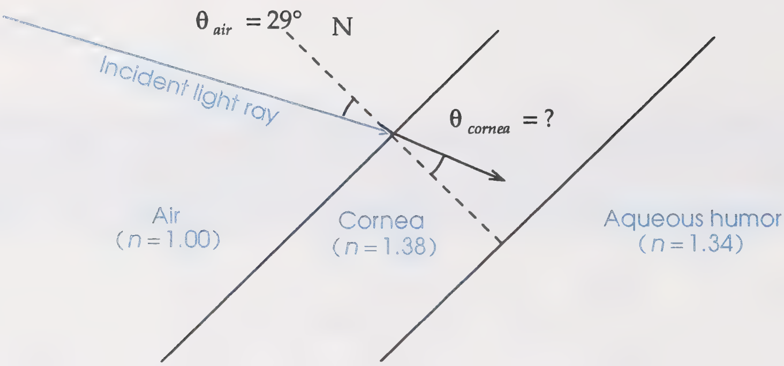


Achromatic lens

7. All colours will reflect at exactly the same angle if the angles of incidence are identical. Refraction, on the other hand, is a change of speed due to a change of wavelength. Different colours will refract at different angles.

8. a. The most refraction occurs at the air/cornea interface since that is where the biggest difference in indices of refraction exists.

b.



c. $\theta_{air} = 29°$

$n_{air} = 1.00$

$n_{cornea} = 1.38$

$\theta_{cornea} = ?$

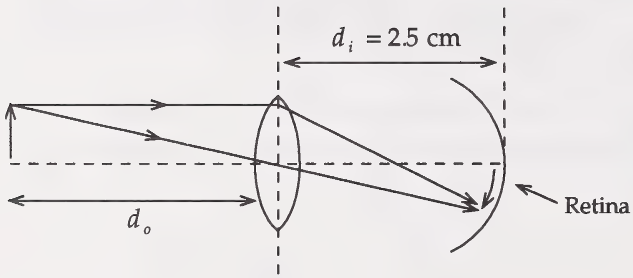
$$\frac{\sin\theta_{air}}{\sin\theta_{cornea}} = \frac{n_{cornea}}{n_{air}}$$

$$\sin\theta_{cornea} = \frac{\sin\theta_{air}\, n_{air}}{n_{cornea}}$$

$$= \frac{(\sin 29°)(1.00)}{1.38}$$

$$\theta_{cornea} = 21°$$

9.



- The closest objects that can be clearly seen are those objects at the near point.

$d_o = 0.25$ m

$d_i = 0.025$ m

$f = ?$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$= \frac{1}{0.25\text{ m}} + \frac{1}{0.025\text{ m}}$$

$$= 4.0\text{ m}^{-1} + 40\text{ m}^{-1}$$

$$\frac{1}{f} = 44\text{ m}^{-1}$$

$$f = 0.023\text{ m}$$

- The furthest objects that can be clearly seen are those objects that are so far away that the distance could be considered infinity.

$d_o = \infty$
$d_i = 0.025 \text{ m}$
$f = ?$

$$\begin{aligned} \frac{1}{f} &= \frac{1}{d_o} + \frac{1}{d_i} \\ &= \frac{1}{\infty} + \frac{1}{0.025 \text{ m}} \\ &= 0 + 40 \text{ m}^{-1} \\ \frac{1}{f} &= 40 \text{ m}^{-1} \\ f &= 0.025 \text{ m} \end{aligned}$$

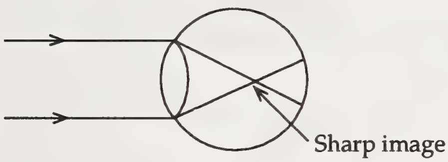
- The range of focal lengths for the eye is 0.023 m to 0.025 m.

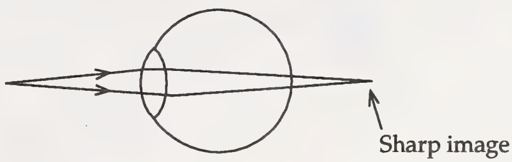
10. The muscles must contract in order to decrease the focal length. This is because d_i is constant (about 2.5 cm) and so f will increase or decrease as d_o does the same in $f = \dfrac{d_i d_o}{d_i + d_o}$.

    The answer to the previous example provides a concrete example of focal length decreasing to view a closer object.

11. People with myopia find that the lens cannot achieve a long enough focal length to bring distant objects into focus on the retina.

    People with hyperopia find that the lens cannot achieve a short enough focal length to bring nearby objects into focus on the retina.

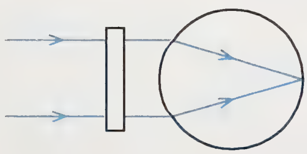




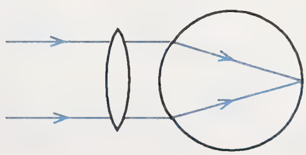
12. The cornea must be transparent, so there can be no blood vessels.

13. If contact lenses are worn too long, then the cells of the cornea will become stressed due to lack of oxygen.

14. a.



Since no change is needed for the top view, the lens is rectangular.



A convex lens is needed for the side view.

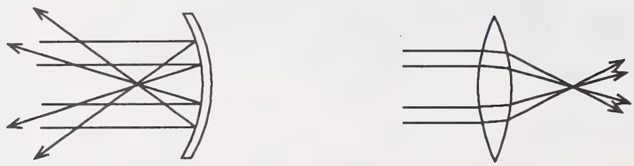
b.

This shape is rectangular when viewed from the top, and convex when viewed from the side.

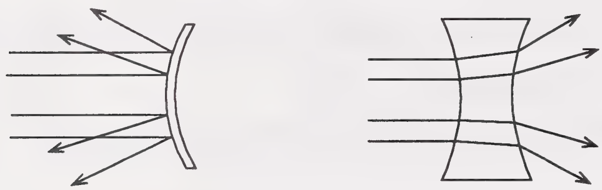
Section 2: Follow-up Activities

Extra Help

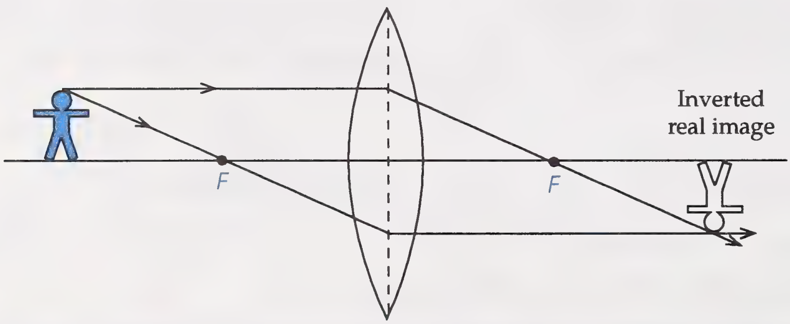
1. a. Both devices cause light rays to converge.



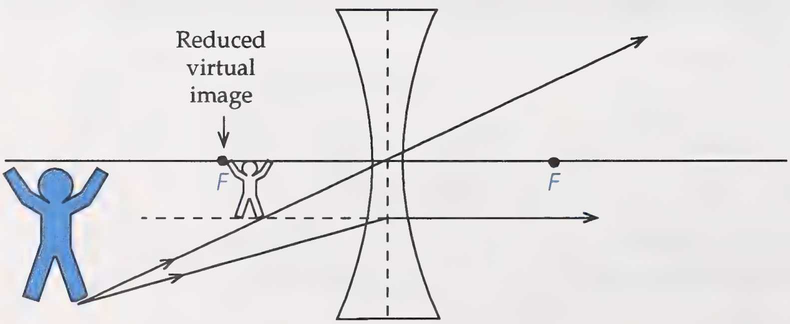
b. Both devices cause light rays to diverge.



2. a.



b.



3. $\frac{h_i}{h_o} = \frac{11\text{ mm}}{11\text{ mm}} = 1.0$

$\frac{d_i}{d_o} = \frac{50\text{ mm}}{50\text{ mm}} = 1.0$

The ratios are equal.

4. Textbook question 14:

$f = 10.0\text{ cm}$
$d_i = 11.0\text{ cm}$
$d_o = ?$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_o = \frac{f d_i}{d_i - f}$$

$$d_o = \frac{(10.0\text{ cm})(11.0\text{ cm})}{(11.0 - 10.0)\text{ cm}}$$

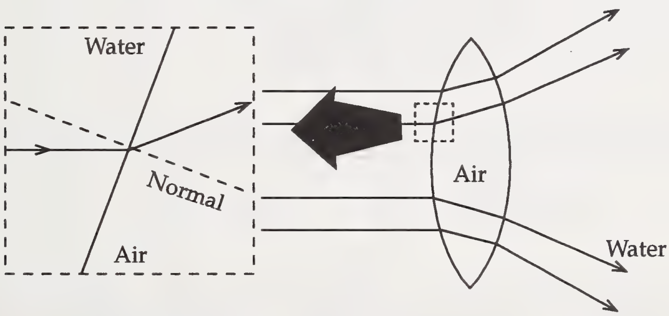
$$d_o = 1.1 \times 10^2\text{ cm}$$

The object needs to be 1.1 m from the lens.

Enrichment

1. a. Textbook question 2.4:

As light enters a medium where it speeds up, it will refract away from the normal. This is the case when the light travels from water into the air.



As light enters the convex air lens, it will refract away from the normal. Individual rays tend to diverge.

b. $f = 22.0\text{ cm}$
$m = -2$

The image created by a photocopier must be a real image. Since a convex lens is being used, the image must be inverted to produce a real image. Since the magnification is 200 percent, the magnification must be -2.

Step 1: $m = \frac{-d_i}{d_o}$

$d_i = -md_o$

$= -(-2)d_o$

$= 2d_o$

Step 2: $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{f} = \frac{1}{2d_o} + \frac{1}{d_o}$

$\frac{1}{f} = \frac{1}{2d_o} + \frac{2}{2d_o}$

$\frac{1}{f} = \frac{3}{2d_o}$

$d_o = \frac{3f}{2} = \frac{3(22.0 \text{ cm})}{2}$

$d_o = 33.0 \text{ cm}$

Since $d_i = 2d_o$,

$d_i = 2(33.0 \text{ cm})$

$d_i = 66.0 \text{ cm}$

2. a. $f_1 = 20$ cm
$t = 10$ cm
$f_2 = -20$ cm
$f = ?$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{t}{f_1 f_2}$$

$$f = \frac{f_1 f_2}{f_2 - f_1 - t}$$

$$f = \frac{(20 \text{ cm})(-20 \text{ cm})}{(-20 + 20 - 10) \text{ cm}}$$

$$f = 40 \text{ cm}$$

b. $t = 0$ since the lenses are in contact
$f = 8.0$ cm
$f_1 = 12.0$ cm
$f_2 = ?$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$f_2 = \frac{f f_1}{f_1 - f}$$

$$f_2 = \frac{(8.0 \text{ cm})(12.0 \text{ cm})}{(12.0 - 8.0) \text{ cm}}$$

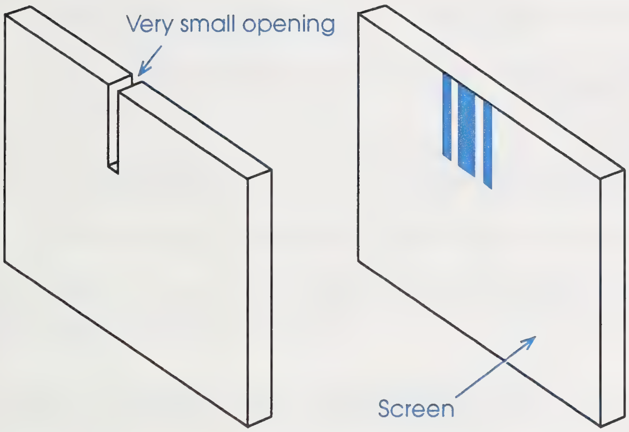
$$f_2 = 24 \text{ cm}$$

3. Suggested answers to this exercise can be found at the back of the enrichment booklet.

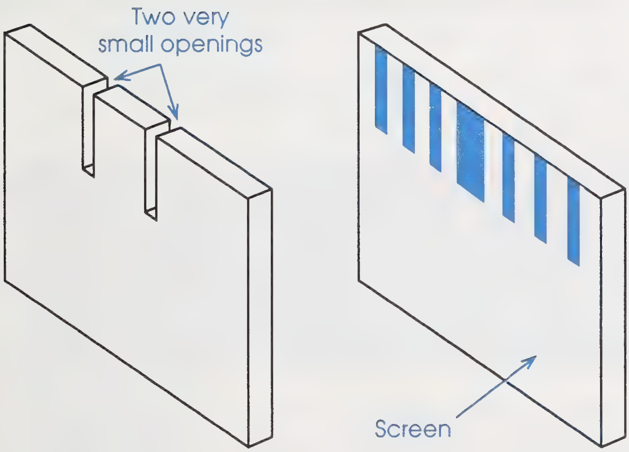
Section 3: Activity 1

1. Newton was one of the greatest physicists that ever lived, so people were very hesitant to take an opposing point of view. Huygens, although a great scientist, did not have nearly the overwhelming prestige that Newton did.

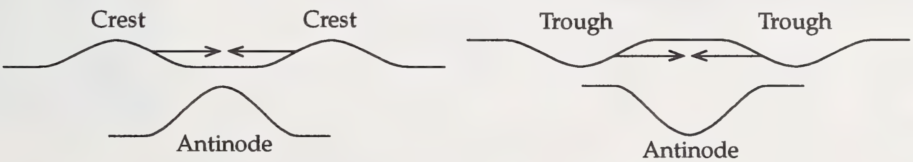
2.



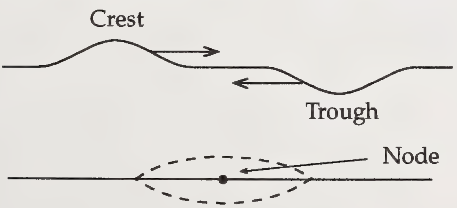
3.



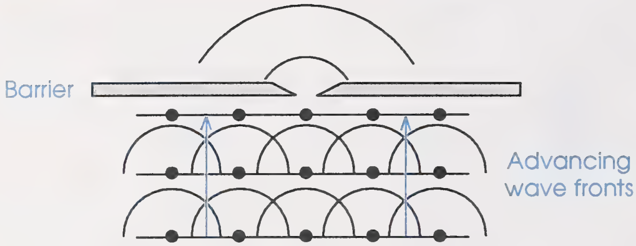
4. Bright lines are due to the constructive interference of light waves. On the video this was demonstrated by crests meeting crests, and troughs meeting troughs, as shown in the following diagram.



Dark lines are due to the destructive interference of light waves. On the video this was demonstrated by crests meeting troughs, as shown in the following diagram.



5.



Each point on a plane wave front could be considered a point source for circular waves. Normally these circular waves interfere with each other so that the sideways portions of the waves cancel each other out. The result is a new straight wave front.

When a wave strikes an opening in a barrier, not all the point sources pass through the opening. The proceeding diagram shows the idealized situation of only one point passing through the barrier. In this case, there are no other point sources to cancel out the sideways portions of the circular wave. The result is a circular wave.

6. The answer to this question can be found in the answer to question 4.

7. The semicircles in Figure 19-2 represent wave crests.

8. The solid red lines represent lines of crests meeting crests and troughs meeting troughs. The result in both cases is the creation of an antinode. This is why these lines are called antinodal lines.

9. The faint dashed red lines represent lines of crests meeting troughs. The result in this case is a node, which is why these lines are called nodal lines.

10. The difference in the two paths is exactly one wavelength.

11. The first approximation is that the angle defined by S_1NS_2 is equal to 90°. The other approximation is that the length of $\overline{PO}$ is the same as L. The formula is still accurate because when L is much larger than d, these approximations are very close to being true.

12. The equation could be written as follows:

$$\frac{2\lambda}{d} = \frac{x}{L}$$

$$\lambda = \frac{xd}{2L}$$

13. $n = 1$

$d = 1.90 \times 10^{-5}\ \text{m}$

$x = 13.2\ \text{mm}$

$= 1.32 \times 10^{-2}\ \text{m}$

$l = 0.600\ \text{m}$

$\lambda = ?$

$$\lambda = \frac{xd}{nL}$$

$$= \frac{(1.32 \times 10^{-2}\ \text{m})(1.90 \times 10^{-5}\ \text{m})}{(1)(0.600\ \text{m})}$$

$$= 4.18 \times 10^{-7}\ \text{m}$$

There are two important things to notice about the solution to this problem.

- The equation used was the version presented in the module, not the version presented in the textbook.
- Your calculator may have at first produced an answer that looked like this 0.000 000 4. To get the correct answer you would have to get your calculator to convert this to scientific notation.

14. The answers to these problems are found on page 679 of your textbook.

Section 3: Activity 2

1. A trough is always found halfway between two crests. Since the white space is halfway between the dark lines, the white spaces must represent troughs.

2. The dark bands represent lines of nodes (nodal lines). The reason for this is that these the dark bands represent locations where crests meet troughs.

3. The bright bands represent lines of antinodes (antinodal lines). The reason for this is that these bright bands represent locations where troughs meet troughs and where crests meet crests.

4.

Order of the Antinode n	Distance Between Sources d (cm)	Distance Between Sources and Antinodes l (cm)	Distance Between Central Antinode and Each Antinode x (cm)	Wavelength λ (cm)	Percent Error (%)
1	3.0	14.85	1.30	0.26	4.0
2	3.0	14.85	2.55	0.26	4.0
3	3.0	14.85	3.85	0.26	4.0
4	3.0	14.85	5.75	0.27	8.0
5	3.0	14.85	6.85	0.28	12

5. This question is answered on the previous chart.

6. This question is answered on the previous chart.

7. This question is answered on the previous chart.

8. Twenty wavelengths were measured to be separated by 5.00 cm. This was done by measuring between 21 consecutive crests.

$$\lambda = \frac{5.00\ \text{cm}}{20} = 0.25\ \text{cm}$$

9. This question is answered on the previous chart.

10. Since this is a prediction, answers will vary. You may have said that as l is decreased, x is decreased.

11. The antinodes got closer together as the value of l decreased.

12. $$\lambda = \frac{xd}{nl}$$

$$x = \frac{n\lambda l}{d}$$

The equation shows that if n, λ, and d are kept constant, decreasing l should cause a proportional decrease in x.

13. Since this question is a prediction, answers will vary. You may have said that as d is decreased, x is increased.

14. The number of nodal and antinodal lines decreases and the lines get further apart from each other.

15. $$\lambda = \frac{xd}{nl}$$

$$x = \frac{n\lambda l}{d}$$

This equation shows that if n, λ, and l are kept constant, decreasing the value of d would have the effect of increasing the value of x.

16. If you checked your answers with the samples presented in the Appendix, you should have been able to confirm both the validity of the equation and the interrelationships between the variables.

Section 3: Activity 3

1. The spacing between the lines is normally about one millionth of a metre.

2. number of lines = 360 lines
distance containing the number of lines = 1 mm
distance between consecutive lines = d = ?

$$d = \frac{1\ \text{mm}}{360\ \text{lines}}$$

$$= \frac{1 \times 10^{-3}\ \text{m}}{360\ \text{lines}}$$

$$= 2.78 \times 10^{-6}\ \text{m}$$

The previous solution indicates the following equation:

$$d = \frac{\text{distance containing the number of lines}}{\text{number of lines}}$$

3. number of lines = 530 lines
distance containing the number of lines = 1 mm
distance between consecutive lines = d = ?

$$\begin{aligned} d &= \frac{\text{distance containing the number of lines}}{\text{number of lines}} \\ &= \frac{1\text{ mm}}{530} \\ &= \frac{1 \times 10^{-3}\text{ m}}{530} \\ &= 1.89 \times 10^{-6}\text{ m} \end{aligned}$$

4. A diffraction grating separates the individual colours to a greater extent, allowing for better measurements.

5. $n = 1$
$x = .353$ m
$l = 1.000$ m
$d = 1.887 \times 10^{-6}$ m
$\lambda = ?$

$$\begin{aligned} \lambda &= \frac{xd}{nl} \\ &= \frac{(.353\text{ m})(1.887 \times 10^{-6}\text{ m})}{(1)(1.000\text{ m})} \\ &= 6.66 \times 10^{-7}\text{ m} \end{aligned}$$

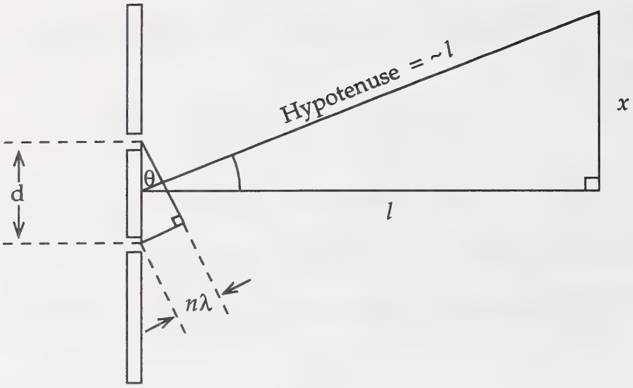
6. Using $\lambda = d \sin\theta$:

$$\begin{aligned} \text{percent error} &= \frac{|\text{theoretical value} - \text{experimental value}|}{\text{theoretical value}} \times 100\% \\ &= \frac{|(6.328 \times 10^{-7}\text{ m}) - (6.28 \times 10^{-7}\text{ m})|}{6.328 \times 10^{-7}\text{ m}} \times 100\% \\ &= 0.76\% \end{aligned}$$

Using $\lambda = \dfrac{xd}{nl}$:

$$\begin{aligned} \text{percent error} &= \frac{|\text{theoretical value} - \text{experimental value}|}{\text{theoretical value}} \times 100\% \\ &= \frac{|(6.328 \times 10^{-7}\text{ m}) - (6.66 \times 10^{-7}\text{ m})|}{6.328 \times 10^{-7}\text{ m}} \times 100\% \\ &= 5.2\% \end{aligned}$$

7.



$$\boxed{\lambda = \frac{xd}{nl}}$$

This equation is based on the idea that both triangles contain the same angle, θ. The value for $\sin\theta$ should be the same for both triangles.

Small triangle

$$\boxed{\sin\theta = \frac{n\lambda}{d}}$$

Big triangle

$$\boxed{\sin\theta = \frac{x}{\approx l}}$$

$$\frac{n\lambda}{d} = \frac{x}{\approx l}$$

$$\lambda = \frac{xd}{n(\approx l)}$$

To arrive at the final equation requires that the hypotenuse of the triangle be equal to l. This approximation is only valid for very small angles, so the equation is only valid for very small angles.

$$\boxed{\theta = \tan^{-1}\left(\frac{x}{l}\right)}$$

$$\boxed{\lambda = \frac{d\sin\theta}{n}}$$

These equations are also based on the idea that both triangles contain the same angle, θ.

This combination of equations does not use the hypotenuse and it does not make the approximation that the hypotenuse is equal to l.

This combination of equations is not limited to only small angles.

8. Textbook question 11:

$$\begin{aligned} d &= 4.00\times10^{-4}\ \text{cm} \\ &= 4.00\times10^{-6}\ \text{m} \\ x &= 16.5\ \text{cm} \\ &= 0.165\ \text{m} \\ l &= 1.00\ \text{m} \\ \lambda &= ? \\ n &= 1 \end{aligned}$$

$$\begin{aligned} \theta &= \tan^{-1}\left(\frac{x}{l}\right) \\ &= \tan^{-1}\left(\frac{0.165\ \text{m}}{1.00\ \text{m}}\right) \\ &= 9.369^\circ \end{aligned}$$

$$\begin{aligned} \lambda &= \frac{d\sin\theta}{n} \\ &= \frac{(4.00\times10^{-6}\ \text{m})(\sin 9.369^\circ)}{1} \\ &= 6.51\times10^{-7}\ \text{m} \end{aligned}$$

9. The following data represents typical student answers. Although your answers may vary slightly, they should be close to these values.

Colour	Distance from Central Antinode (The Lamp) to First Order Antinode x (m)	Distance Between Source (Grating) and Lamp l (m)	Diffraction Angle θ (°)	Distance Between Lines on Grating d (m)	Wavelength λ (m)
Orange	0.335	1.000	18.5	1.887×10^{-6}	5.99×10^{-7}
Yellow	0.323	1.000	17.9	1.887×10^{-6}	5.80×10^{-7}
Green	0.304	1.000	16.9	1.887×10^{-6}	5.49×10^{-7}
Blue	0.263	1.000	14.7	1.887×10^{-6}	4.79×10^{-7}

10. number of lines = 5300
distance containing the number of lines = 1 cm
distance between consecutive lines = d = ?

$$d = \frac{\text{distance containing the number of lines}}{\text{number of lines}}$$
$$= \frac{1\text{ cm}}{5300}$$
$$= \frac{1 \times 10^{-2}\text{ m}}{5300}$$
$$= 1.887 \times 10^{-6}\text{ m}$$

11. The values for the angle θ and wavelength are shown on the previous chart.

12. The values should all be within this range. The values from smallest wavelength to largest should be blue, green, yellow, and orange.

13. Textbook question 8:

$$\begin{aligned} \lambda &= 400\text{ nm} \\ &= 400 \times 10^{-9}\text{ m} \\ &= 4.00 \times 10^{-7}\text{ m} \\ l &= 90\text{ cm} \\ &= 0.90\text{ m} \\ n &= 1 \\ x &= 0.30\text{ cm} \\ &= 0.0030\text{ m} \\ d &= ? \end{aligned}$$

$$\begin{aligned} \theta &= \tan^{-1}\left(\frac{x}{l}\right) \\ &= \tan^{-1}\left(\frac{0.0030\text{ m}}{0.90\text{ m}}\right) \\ &= 0.191° \end{aligned}$$

$$\lambda = \frac{d \sin\theta}{n}$$
$$\begin{aligned} d &= \frac{n\lambda}{\sin\theta} \\ &= \frac{(1)(4.00 \times 10^{-7}\text{ m})}{\sin(0.191°)} \\ &= 1.199 \times 10^{-4}\text{ m} \\ &= 1.2 \times 10^{-4}\text{ m} \end{aligned}$$

Textbook question 14. a.:

$$\begin{aligned} \lambda &= 632.8 \text{ nm} \\ &= 6.328 \times 10^{-7} \text{ m} \\ l &= 4.0 \text{ m} \\ x &= 21 \text{ mm} \\ &= 2.1 \times 10^{-2} \text{ m} \\ d &= ? \end{aligned}$$

$$\begin{aligned} \theta &= \tan^{-1}\left(\frac{x}{l}\right) \\ &= \tan^{-1}\left(\frac{2.1 \times 10^{-2} \text{ m}}{4.0 \text{ m}}\right) \\ &= 0.3008° \end{aligned}$$

$$\begin{aligned} \lambda &= \frac{d \sin\theta}{n} \\ d &= \frac{n\lambda}{\sin\theta} \\ &= \frac{(1)(6.328 \times 10^{-7} \text{ m})}{\sin(0.3008°)} \\ &= 0.000\,1205 \text{ m} \\ &= 0.012\,05 \text{ cm} \end{aligned}$$

In 1 cm, the number of ridges could be calculated as follows:

$$\begin{aligned} \text{number of ridges} &= \frac{1.00 \text{ cm}}{0.012\,05 \text{ cm}} \\ &= 83 \text{ ridges} \end{aligned}$$

Textbook question 14. b.:

Step 1: Find the number of ridges.

- Since the record turns at $33\frac{1}{3}$ r/min, there must be $33\frac{1}{3}$ ridges passed in 1 min.
- $\dfrac{33\frac{1}{3} \text{ ridges}}{\text{minute}} \times 4.01 \text{ min} = 133.7 \text{ ridges}$

Step 2: Find the number of ridges in 1.0 cm.

$$\frac{133.7 \text{ ridges}}{1.6 \text{ cm}} = \frac{x}{1.0 \text{ cm}}$$

$$\begin{aligned} x &= \frac{(133.7 \text{ ridges})(1.0 \text{ cm})}{(1.6 \text{ cm})} \\ &= 83.5 \text{ ridges} \\ &= 84 \text{ ridges} \end{aligned}$$

14. Curved Mirrors and Lenses:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Interference Patterns:

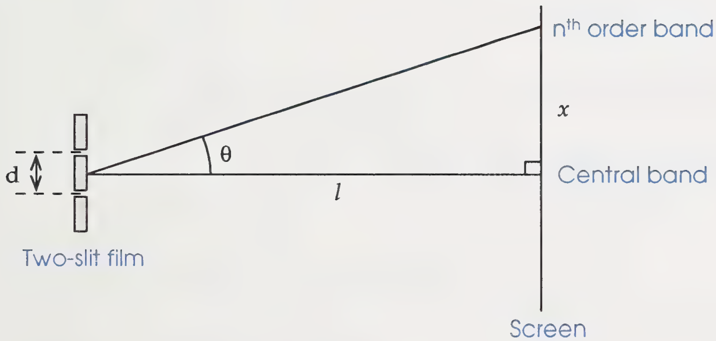
$$\lambda = \frac{xd}{nl} \text{ (valid for small values of } \theta)$$

$$\lambda = \frac{d \sin \theta}{n}$$

Section 3: Follow-up Activities

Extra Help

1. a.



b. The variable n is the number of intervals between the central bright line and the line being observed. The variable λ is the wavelength of the incident light.

2. a. $x = 5.25$ cm
$d = 2.85 \times 10^{-3}$ cm
$l = 125.0$ cm
$n = 2$
$\lambda = ?$

$$\lambda = \frac{xd}{nl}$$

$$\lambda = \frac{(5.25 \text{ cm})(2.85 \times 10^{-3} \text{ cm})}{2(125.0 \text{ cm})}$$

$$\lambda = 5.99 \times 10^{-5} \text{ cm}$$

$$\lambda = 599 \text{ nm}$$

b. $x = 5.25$ cm
$d = 2.85 \times 10^{-3}$ cm
$l = 125.0$ cm
$n = 2$
$\lambda = ?$

$$\theta = \tan^{-1}\left(\frac{x}{l}\right)$$

$$= \tan^{-1}\left(\frac{5.25 \text{ cm}}{125.0 \text{ cm}}\right)$$

$$= 2.405°$$

$$\lambda = \frac{d \sin \theta}{n}$$

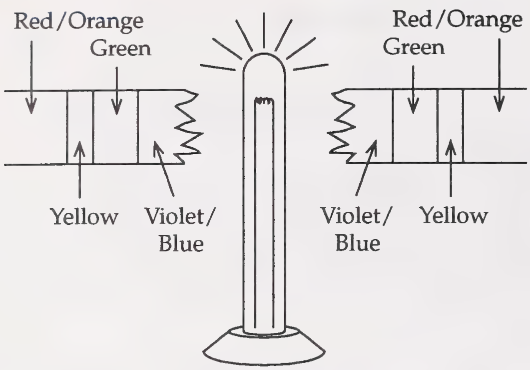
$$= \frac{(2.85 \times 10^{-3} \text{ cm})(\sin 2.405°)}{2}$$

$$= 5.98 \times 10^{-5} \text{ cm}$$

$$= 598 \text{ nm}$$

c. The angle θ is only 2.405°. For such a small angle, the approximations of the equation $\lambda = \frac{xd}{nl}$ give an answer very close to the actual value.

3.



Enrichment

1. a. This value will depend on the gravity that you use. A typical value is shown.

$$\begin{aligned} \text{distance} &= \frac{\text{distance containing the number of lines}}{\text{number of lines}} \\ &= \frac{1\text{ cm}}{5300} \\ &= \frac{1\times10^{-2}\text{ m}}{5300} \\ &= 1.887\times10^{-6}\text{ m} \end{aligned}$$

b. The measurements of x and l will depend on the size of aquarium that you use. The following values are typical.

$$x = 8.0\text{ cm}$$
$$l = 31.2\text{ cm}$$

c. The following calculations are based on the sample data provided.

$$x = 8.0\text{ cm}$$
$$l = 31.2\text{ cm}$$
$$d = 1.887\times10^{-6}\text{ m}$$

For a helium/neon laser the wavelength of the light produced has a wavelength of 632.8 nm in air.

$$\begin{aligned} \lambda_{air} &= 632.8\text{ nm} \\ &= 6.328\times10^{-7}\text{ m} \end{aligned}$$

Step 1: Find θ.

$$\theta = \tan^{-1}\left(\frac{x}{l}\right)$$
$$= \tan^{-1}\left(\frac{8.0\text{ cm}}{31.2\text{ cm}}\right)$$
$$= 14.38°$$

Step 2: Find the wavelength in water.

$$\lambda_{water} = \frac{d \sin\theta}{n}$$
$$= \frac{(1.887\times10^{-6}\text{ m})(\sin 14.38°)}{1}$$
$$= 4.686\times10^{-7}\text{ m}$$

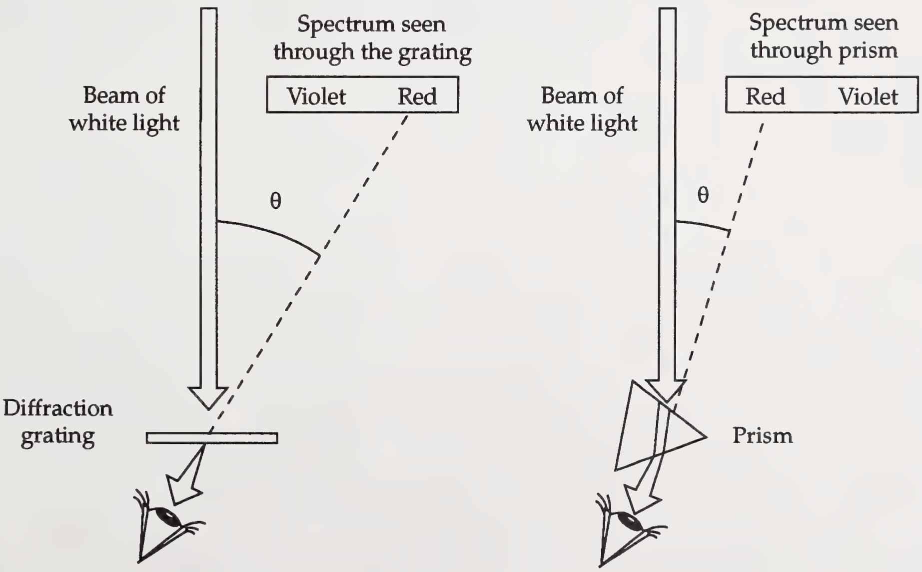
Step 3: Find the speed in water using Snell's law.

$$\frac{v_{air}}{v_{water}} = \frac{\lambda_{air}}{\lambda_{water}}$$
$$v_{water} = \frac{v_{air}\lambda_{water}}{\lambda_{air}}$$
$$= \frac{(3.00\times10^{8}\text{ m/s})(4.686\times10^{-7}\text{ m})}{(6.328\times10^{-7}\text{ m})}$$
$$= 2.22\times10^{8}\text{ m/s}$$

This value is very close to the actual value of 2.26×10^{8} m/s.

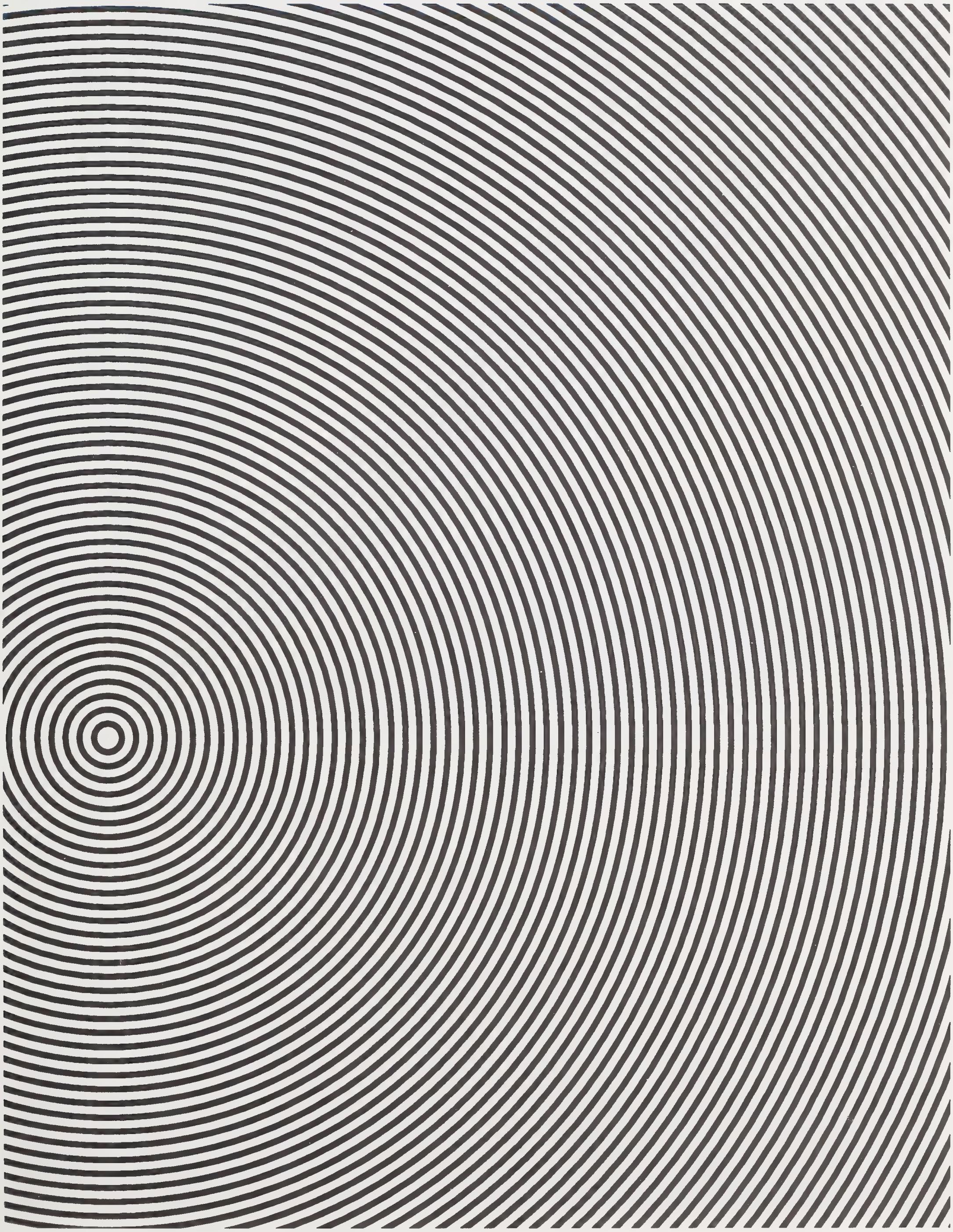
d. This question is answered in part c.

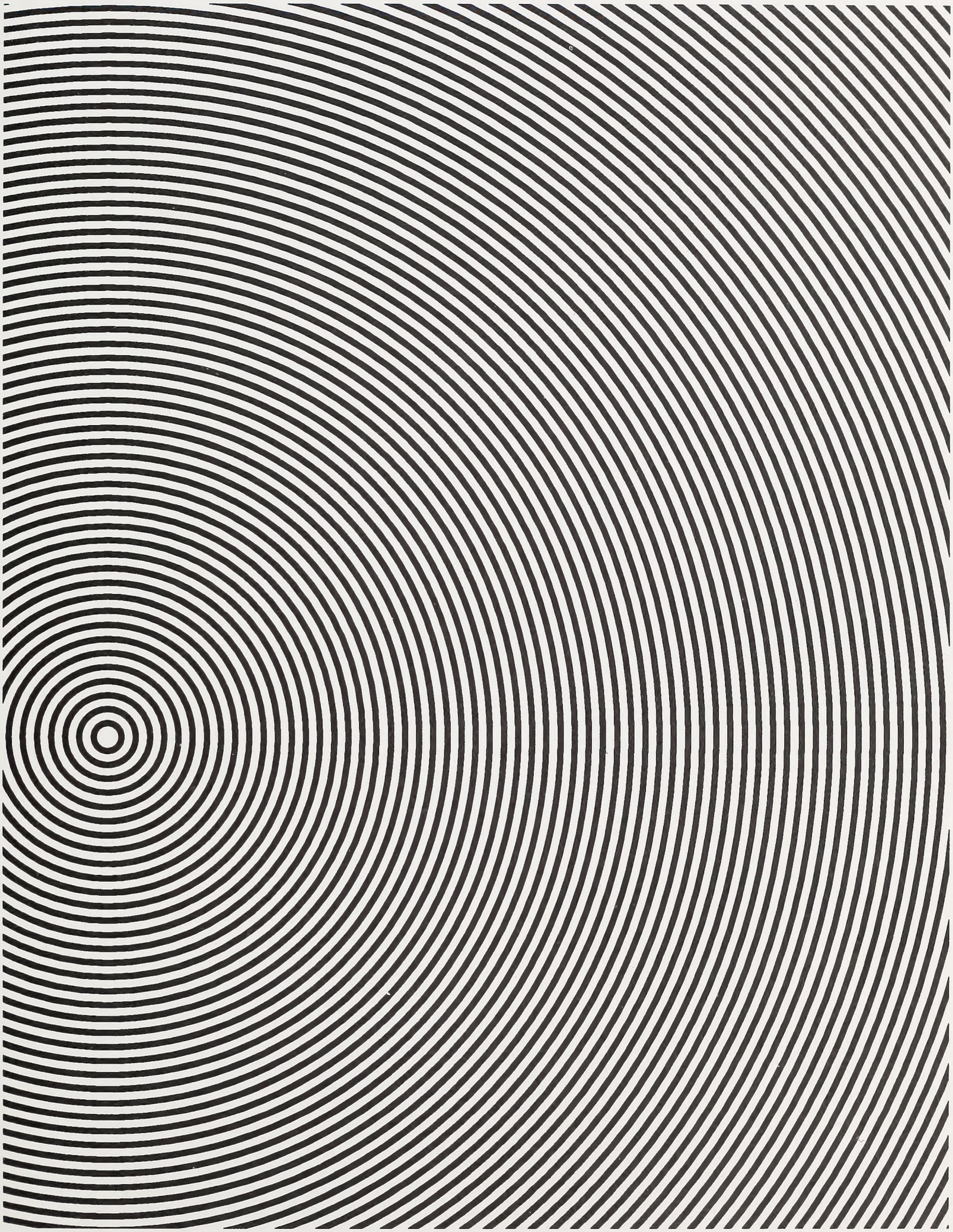
2. a. The red light, having a longer wavelength, will diffract more if there is a grating. However, if it is a prism, the shorter wavelength of violet will refract the most.



As shown in the preceding diagram, a spectrometer made with a grating will have red light make the greatest angle to the incident beam, while a spectrometer made with a prism will have violet light make the greatest angle.

b. It would be easier to resolve two adjacent stars if the blue filter were used. The blue light has a smaller wavelength and would therefore create a smaller diffraction pattern. A smaller pattern means that more details could be resolved and individual stars could be more easily counted.





Physics 20

Student Module Booklet
Module 7

L.R.D.C.
Producer

1993